AN INVESTIGATION OF ELBOWS AS A MEANS FOR MEASURING FLOW OF WATER

A THESIS

SUBMITTED BY

CHARLES POMEROY KIDDER

AND

WILLIAM JACOB RHEINGANS

AND

CHRISTOPHER ARMIN WIEPKING

FOR

THE DEGREE OF BACHELOR OF SCIENCE

CIVIL ENGINEERING COURSE

University of Wisconsin

1920

TABLE OF CONTENTS

INTRODUCTION

An attempt has been made in this thesis to determine the possibility of using an elbow as the means for measuring the quantity of flow through a pipe line. As far as is known, this form of meter has never been used in any practical work, nor has any experimental work been done upon it. The writers are therefore stepping into a new and untried field of research which accounts for some of the departures from a definite plan of procedure. It is nearly impossible to tell along what lines valuable information might be developed.

The advantages of using such an elbow meter, as it may appropriately be called, lies in the ease and economy with which it may be set up in the field where other means for measuring flow would be out of the question. If used under the proper conditions, results as acurate as those of the more expensive venturie meter can be obtained.

In this work, only a few elbows were calibrated, and the acurracy of the results were studied. The limited extent of the work prevented the drawing of any conclusions as to the relations of the meter coefficients in the various setups.

A great deal of research work could be done in studying the variation of the elbow meter coefficient under various changeable conditions such as diameter of pipe line, length of straight pipe leading up to and away from the elbow,

position of elbow meter, that is whether horizontal or vertical, and velocity of flow.

THEORY

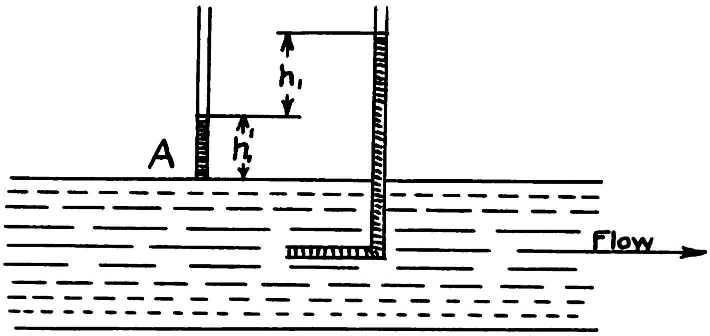


Fig. 1

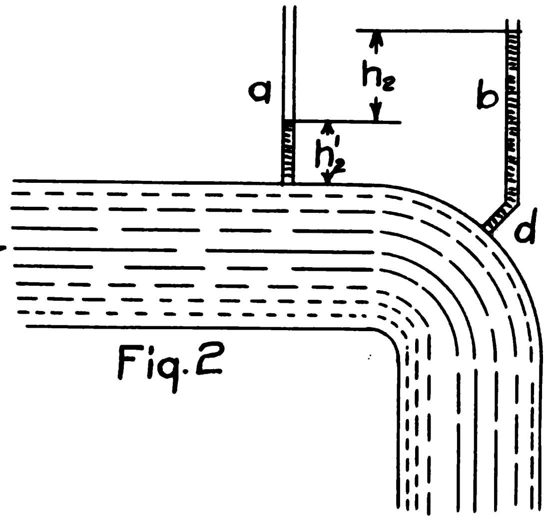


Fig. 2

Water flowing through a pipe has an effective head at any section (A Fig 1) which involves both pressure and velocity of flow. If a piezometer is inserted at right angles to the axis of a pipe, the water will rise to a height equal to the pressure head. (h_1' Fig 1) The introduction of a pitot tube will cause the water to rise to a point $h_1' + h_1$ where h_1 is the velocity head equal to $V^2/2g$. (SeeFig 1.)

If instead of using a pitot tube, the pipe is tapped at an elbow, the water will rise to a height of $h_2' + h_2$ where h_2' is the pressure head and h_2 is some function of $V^2/2g$. (See Fig 2.)By tapping the pipe a short distance in front of the elbow, the pressure head can be measured and h_2 obtained by finding the difference in head of the two columns of water. When these two tubes (a and b Fig 2) are placed close together, the pipe friction loss is negligable, and since there is no other quantity involved, the difference in head must be some function of the velocity.

$h_2 = c\ V^2/2g$ where c is the constant which is to be determined experimentally. The tube "b" is introduced at an angle of 45 degrees with the direction of flow and therefore it is to be expected tht "c" will be less than one, unless the conditions incident to the flow of the water through the elbow are such as to produce a large pressure at "d".

DESCRIPTION OF APPARATUS

Different settings of apparatus were used in obtaining the data in this thesis for the 30-inch, 8-inch, 6-inch, and two separate 4-inch settings. In most of the work, the apparatus was used as permanently installed in the main floor of the laboratory, and in the cases where new arrangements of piping were necessary, temporary settings were made and removed after the completion of the tests.

Calibration of 30-inch Elbow Meter:

For the 30-inch calibration, the large centrifugal pump in the pumping pit of the laboratory was used. The outfit consists of a 30-inch centrifugal pump, directly connected to and driven by a two-cylinder, vertical, simple type steam engine rated at 150 H. P., and the necessary piping and weir channel. The supply water was drawn up from the intake well through the 30-inch suction pipe of the pump. The suction lift to the axis of the pump was 9 feet. The water was discharged through the 30-inch line leading from the pump to the receiving basin of the large weir channel. The 30-inch elbow which was calibrated in this test, was the elbow in the discharge line. The gage used was a two-column water gage, one of the columns connected to a piezometer tapped into the pipe just above the elbow flange joint, and the other in the midpoint of the outer side of the elbow. The following diagram shows the positions of the two piezmmeters as set in all these elbow calibrations:

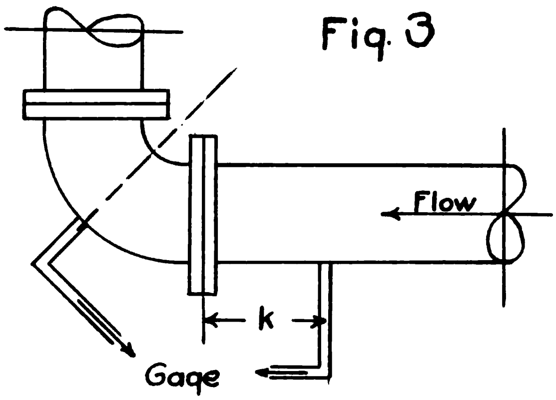


Fig. 3

Table of values of "k" (Fig. 3)

Set-Up	Value of "k"
30" Elbow	
8" Elbow #1	
8 Elbow #2	
6" Elbow #1	
4" Elbow #2	
4" Elbow #1	

A diagram of the water gage which was used in all the tests is included in the drawing (elevation) of the 6-inch set-up, Plate 3, appendix. The water delivered by the pump was directed from the receiving basin down the large flume and into the weir channel, as indicated by the line of arrows in the diagram of the hydraulic laboratory, plate 1. The quantity of flow was measured by the 10-foot weir located in the lower floor of the laboratory. The readings of head on the weir were taken from the two hook gages as permanently installed. The discharge from the weir returned the water to the lake through the tailrace.

Calibration of 8-inch Elbow meter:

In connection with the 8-inch set-up, the water was obtained from the large reservoir. Two views of the 8-inch apparatus are shown on plate 2. The permanent 12" main located above the turbine gates in the laboratory supplied thw water. A reducing "T" was used to connect the 8" pipe tp the 12"line. This was arranged as shown in the plan view to discharge into the small weir channel. Two 8-inch elbows were included in the setting, one horizontal, and the

other vertical; both of them were calibrated, and the same typical gages and piezometer connections were used as in the 30-inch test. The quantity of flow was measured by means of the 3 1/2 foot weir at the head end of the channel. The direction of flow is indicated on the drawing by means of the small arrows.

Calibration of 6-inch Elbow Meter:

Plate 3 shows the arrangement of apparatus used in the six-inch calibration. The main piebes of apparatus are the motot, the pump, gage, and the north weir box. The motor and the pump are a permanent installation in the laboratory. The pump is a 6-inch centrifugal machine, belt driven, and drawing its supply from the intake well. It is in almost daily use, for it is ordinarily used for filling the large reservoir of the laboratory system. The 6-inch elbow which was calibrated is located on the discharge line about five feet from the shaft of the pump, and is set in a vertical position,being a part of the line connecting the pump to the main which is suspended from the ceiling of the laboratory and which runs lengthwise through the building. The piezometer connections and the water gage are shown in the elevation. The water was discharged into the north weir box by closing the valves in the ends of the main line and by opening the valves from the main line to the weir box and from the discharge line from the pump to the main line. Thus the water was shunted across through the existing main system. The quantity of

flow was measured by observing the readings of the hook gage of the north weir box.

Calibration of 4-inch Elbow Meter:

Setting #1

An existing 4" lead from the 8" main above the pumping pit was arranged for this setting, the pipe discharging into the north weir box. The pipe line was rather complex in arrangement, so that turbulent flow conditions affected the calibration results and introduced large errors. As indicated in the diagrams for setting #1 on plate 2, a portion of the pipe line formed a loop. The calibration of this elbow brought out the fact that to get satisfactory results with this form of meter, there must be a considerable length of pipe leading up to and away from the elbow.

Setting #2

The large errors obtained in the 4-inch elbow meter indicated the desirability of running another experiment on the same elbow but with different set-up conditions. A 4-inch setup had already been used for some other work and we simply put our elbow into the line and connected our gage. This set-up is a good example of the ease with which this meter may be set up. The arrangement was as designated in the plan of setting #2, plate 2. The supply was taken from the 8-inch main in the center of the laboratory, and led down through a reducer and a long section of pipe to the 4-inch elbow #2, which was calibrated. The

discharge line led the water back to the south weir box, from which the quantity of flow was taken by means of hook gage readings.

METHOD OF EXPERIMENTING

Reading of Water Gages:

The same gage was used in all of the experiments except that in the 8-inch run an additional gage had to be used for the vertical elbow. (See plate 2) The difference in head was all that was required, and therefore the gages were put under air pressure whenever the head became so great as to rise out of the tube. It was found necessary to dampen the water columns considerably because of their tendency to jump up and down. Even when the valves on the piezometer connections had been closed as far as practicable, there was still some motion. However, a special effort was made to have the two columns move in unision, that is to have them go up together and come down together so that there would be no lag. This was accomplished by adjusting the valve openings in the connections between the elbow and the gage.

The gages were supplied with vernier pointers which enabled the gages to be read to the nearest thousanth of a foot. In order to obtain a more accurrat value of the difference in the head, both pointers were set at practically the same time. Ordinarily, the readings werectaken at the beginning of the run and at the end of every minute; thus a four minute run would furnish five readings. At the beginning of each set of runs, the gages were flushed thoroughly so as to let out all the trapped air. Since a large

part of the accurracy of the work depended upon the reading of the water gages, great care was taken to get correct values.

Control of the Water Supply:

30-inch Elbow Meter

The water was pumped by a centrifugal pump and the discharge was controlled by regulating the speed of the steam engine at the throttle. The man at the weir gage could determine when a sufficient change in discharge had been reached and when conditions had become settled. He could then make it known to the man at the throttle. After a little practice, the latter knew just about how much to change the throttle in order to obtain a certain change in discharge. (See Plate 1.)

8-inch Elbow Gage:

A centrifugal pump operated by an electric motor supplied the water for this test. For velocities over six feet per second, the discharge was controlled by varying the speed of the motor with a water rheostat. A downstream valve was used to control the discharge when lower velocities were desired. This valve was kept wide open at all other times. (See Plate 3.)

4-inch and 6-inch Elbow Meters:

The water for the first of the 4-inch elbows was obtained from the university pumping station. The discharge was controlled by a valve upstream from the gage connections. (See Plate 2.) The flow was rather unsteady because of the variation in pressure maintained at the pumping station.

It was found necessary to start extra pumps when the flow was at the maximum. The water for the 8-inch and the second setting of the 4-inch elbow was obtained from the reservoir which furnished a head of 50 feet. The rate of discharge was controlled by an upstream valve. (See Plate 2) The flow was very steady because of the constant head maintained in the reservoir.

In all the experiments except the 8-inch elbow, a series of runs were made starting with a slow velocity and were gradually increased until a maximum was reached. The velocity was then decreased again until the minimum was reached. If, after the points had been plotted, it was found necessary to take additional points, they were immediately run.

Measurement of Discharge:

The discharge was measured in all cases by means of weirs. For the 30-inch elbow meter test, use was made of the ten-foot weir with its two hook gages, one on each side of the channel of approach. This weir was calibrated in 1917-18 by C. N. Ward and H. Brock. Their curve was used in computing the quantity. (See Sheet 19.)

The 6-inch elbow test and the first setting of the 4-inch elbow, the quantity was measured in the north weir box with the 10" rectangular weir. This calibration was made in 1918 by C. D. Diedrich. His curve was assumed to be alright. (See Sheet 17.)

The discharge for the 8-inch runs was measured in the

3 1/2 foot weir calibrated in 1920 by Tabor and Sloan. Their tables of Q were used. (See Sheet 20 for Q Curve)

The second setting of the 4-inch elbow was run through the south weir box with the 12" rectangular weir calibrated by C. T. Wiskocil and Ward and Brock. Their curve was used. (See Sheet 18.)

In all the above measurements, a hook gage reading to one ten thousanth of a foot was used to measure the head on the weir. The reader, Kidder, would take a measurement at every high and low point of the fluctuating wave in the channel. In order to eliminate the lost motion in the gage, the hook was always raised up to the level of the water in reading. The zero reading of the gage was frequently determined, either before or after a series of runs. Since this factor could greatly alter the validity of the work, great care was always taken to get the zero reading correct. The zero elevation of the water in the channel was found by holding an electric lamp above the crest of the weir and by noting the image of the lamp in the water. The image of the lamp filaments was only undistorted when the water was level with the crest of the weir.

Length of Runs:

The experiment on the 30-inch elbow was the only one in which exceptionally long runs were made. These runs varied from 20 minutes down to four minutes with a six to seven minute interval between runs. The long interval between runs was required because of the fact that the discharge channel was so long that it took some time for

conditions to become settled to regular flow.

In the 8-inch series, it was found necessary to use rather short runs of three minutes duration because the reservoir was not of sufficient capacity to warrant a longer run.

All the other runs were from four to five minutes in length with a two or three minute interval betweenn runs. This gave ample time for conditions to adjust themselves and to get a correct reading. The interval between runs was usually determined by the man reading the hook gage on the weir. He could tell when the rate of flow had become constant.

COMPUTATIONS

An adding machine and a ten-inch slide rule were used in the computations. From six to ten readings of the gage and weir were taken at equal intervals during the run, the number depending on the length of the run. The arithmetical averagesof the readings of both the legs of the water gage were found and the difference in these averages was taken as the velocity head of the water at the elbow. The head on the weir was taken as the arithmetical average of the individual readings during a run, after a correction had been made for the zero reading of the hook gage. Quantity of flow was taken from weir calibration curves which had been previously made by students and instructors. Copies of the weir calibration curves are bound here. (See Sheets 17 to 20.)

In the 30-inch setup, the 10-foot channel and weir were used. It was found advisable to make a correction for the leakage through a poorly constructed bulkhead. All the leaking water was diverted into a 16" channel in which a rough board weir had been placed with which the quantity of leakage was estimated. This correction was added to the quantity as taken from the 10-foot weir calibration curve.

With the quantity of flow known, the velocity and the velocity squared of the water running through the elbow was computed. The velocity was found by dividing the quantity by the area of crossection of the elbow. (In each case,

the area of crossection was determined accurrately by measuring the diameter of the pipe with calipers.)

The formula is: $V = \frac{Q}{A}$

Curves were drawn with the readings of the gage as ordinates and with velocities squared as abscissae. The reason for doing this was that theoretically these two variables should have a straight line variation, and the curve could be quite accurrately drawn. After the points were plotted, a line was drawn through the origin and the point representing the avarage ordinate and abscissa of all the experimental points. The equasion of this line would be $H = kV^2/2g$, where H is the reading of the gage in feet, V is the velocity in feet per second, g is the gravitational constant (32.2), and k is the coefficient of the gage. The value of k was found by multiplying the slope of the line drawn in by 2g.

With the equasion known which represented the relation between H and V^2, the equasion was derived for the relation between H and Q.

$$H = k\frac{V^2}{2g}$$

$$V = \frac{Q}{A}$$

$$H = k\frac{Q^2}{A^2 2g}$$

k, A, + g are constants

$$H = C'Q^2$$

$$Q = C\sqrt{H}$$

DISCUSSION OF RESULTS

In making a study of the data obtained, the velocities squared were plotted against the differnece in head of the water gage. This curve, according to the theory, should be a straight line. It was found that such was the case, the straight line being the best curve that could be drawn through the points. The center of gravity was computed, and the line was then drawn through this point and the origin. Percentages of error of velocity as noted from the line thus drawn were plotted against the velocities. A study of these curves (Sheets 5 to 9) indicates that there might be a slightly different curve than the straight line for H and V^2, because the errors run from a plus in the low velocities to a minus in the high velocities. This holds true only when the general results are good. This variation, however is so slight that it seems impracticable to consider it or to attempt to use any relation other than the straight line relation. Following is a discussioh of the various results obtained in the different experiments:

1. Accuracy and Percent Error:

At the start, it was the object to only run an experiment on the 20-inch elbow. With the plotting of the first thirty runs, it looked as though the H - V^2 curve would turn out to be a parabola. However, a second set of runs threw the points way off the curve. These runs were all made between December 18 and 22. Another set of runs were made between February 9 and 12. These points were still

farther from any sort of curve. (SEE Sheet 10.) At this time, the level of the lake was very low, and no high velocities could be obtained due to a lack of water. Even at the smaller velocities, the pump was drawing air which,ade accurrate work impossible. It was impossible to remedy this and it was finally concluded that the pump had drawn more or less air in all the runs. Therefore, no attempt was made to analyze the data. The curve (Sheet 10) shows that the effect of the drawing of air was not so much upon the quantity of discharge as upon the water gage. As soon as any large quantity of air would be drawn into the pump, it would effect the water gage in such a manner as to form a pressure cushion and have a much smaller difference in pressure in the water columns than would otherwise result. For the smaller discharges the effect would be just reversed, since the quantity of discharge would not be as great as the water gage indicated. When the points representing the smaller velocities were taken into consideration, it was found that the coefficient of the elbow meter was greater than one. This shows at once that the results were not valid.

It might be stated here that before another attempt is made to run a similar experiment on the 30-inch elbow, the channel and the basin would have to be deepened and an extension added to the suction pipe.

6-inch Elbow Gage:

This experiment gave very good results as compared to the 30-inch elbow. One slight disadvantage to the accurracy

of the work was the proximity of the elbow to the pump. (Plate 3) The water had no time to quiet down before it reached the elbow, and the turbulent flow had a bad effect especially in the lower velocities. (See Sheet 7) At a velocity of from three to four feet per second, the percentage of error was plus or minus six percent. This error dropped to two percent at a velocity of nine feet per second.

First setting of the 4-inch Elbow:

These runs gave some very interesting results as compared to a second experiment with the same elbow. The whole arrangement was of a wholly different nature from any other that was used. (See Plate 2) A double elbow was located a short distance upstream from the elbow meter, with the controlling elbow between the double elbow. The pipe below the elbow meter was short and sloped upward thus putting the elbow on a slant. These conditions naturally caused a great disturbance in the water and accounts for the large discrepancies. The water was obtained from the university pumping station which meant that there was a great fluctuation in the pressure. This was noticable in the water gage and also on the weir. Since the length of the run was considerable, this fluctuation would not allow uniform conditions during the run, and there was an appreciable error. The percentage of error varied from plus or minus 20 at a velocity of four feet per second to five percent at a velocity of fourteen feet per second.

Second Setting of 4-inch Elbow:

The second setup was made in order to study the effect of varying conditions upon the accurracy of results and upon the coefficients. Since conditions for this setup were more favorable for steady flow than the first setup with the same elbow, (Plate 2) better results were expected and obtained. Velocities of eight feet per second gave results well within a limit of plus or minus two percent. The coefficient also differed by nearly a hundred percent in the two cases.

In general, the best results were obtained at high velocities which indicates that the greatesy error to contend with was that of reading the water gage and the weir. This is true because the water gage and the discharge cannot be read as accurrately at low velocities as at high, and a small error in reading at the high velocities would not make so much percent error as that same constant error in the low velocities.

The 8-inch Elbow Meter:

Two elbows were used for this experiment, one vertical and the other horizontal. (Plate 2) Since setup conditions were ideal, ther errors were small. At the low velocities, four feet per second, the error was plus or minus four percent. The higher velocities gave better results. Above eight feet per second, the error was well within two percent.

Variation of Coefficients in the Same Elbow under Different Conditions:

A comparison of the figures on plate 2 showing the 4-inch settings numbers one and two, will show how conditions will effect the results. It also shows the variation which is to be expected in the coefficients. The first setting gave a coefficient of .32, and the second gave .64. This is a variation of 33% from the mean and it indicates that elbow meters should be calibrated where the conditions give disturbances close to the gage and a fluctuating water supply prevails.

Variation of Coefficients in different elbows:

The coefficients in the different elbows vary from 2 to 17 percent from a mean. This at once shows that it would be impossible to use the same ceefficient for elbows of different sizes. A study of the curves on sheet 16 shows that there is no simple relation between size of elbow and coefficient. The curve does show the variation in coefficient which is to be expected. This necessitates the determination of the coefficient for each size of elbow to be used in measuring flow.

Variation of Coefficients in Horizontal and Vertical Elbows in the same Line:

The variation of the coefficient in a horizontal and a vertical elbow of the same size in the same line was small, being about two percent from the mean. Since the conditions

for both these elbows was practically the same, this is an example of what the different elbows of the same size will do under similar conditions. By similar conditions it is meant that the length of pipe straight before and beyond the elbow is the same, and the water supply is the same. In this set of runs, the water supply was from the reservoir. A very steady flow was obtained.

CONCLUSIONS

From a study of the data obtained in these experiments as presented in detail and froma study of the curves, it is concluded that the elbow meter may be used to advantage in many instances. With a steady flow, with a reasonably long length of pipe upstream and downstream from the elbow meter, and with a well calibrated elbow, the error need not be greater than two percent. This is as accurrate as the venturie meter. For practical field work with an uncalibrated elbow, the error will probably run up to five or six percent. This follows from the fact that in the ranges of velocities used in practical work, the error in a single calibrated elbow meter is as hgih as two or three percent. Where the elbow is not calibrated under the conditions where it is used, an error of 1.5 to 2.5 percent may be expected in the coefficient.

The elbow meter could be used in irrigation work where a ten percent error is allowable and a five percent error is of no consequence. Its great advantages are the simplicity of construction, and the low cost of installation. It can be set up in a very short time when the occasion demands and then might be equipped with an automatic reading and registering device.

It is the suggestion of the writers that future experimenters calibrate pipes of larger diameter, and also check up the results obtained in this thesis.

APPENDIX

SAMPLE DATA SHEET

EXPERIMENT ON Calibration of 30" elbow

DATA BY Rheingans, Wiepking, and Kidder.

DATE OF EXPERIMENT December 18, 1919.

GENERAL DATA: Zero reading gage #1 (north) = .040

Zero reading gage #2 (east) = .014

Q correction due to leaking water = .07 S.F.

(Weir Data)

Run No.	Time	Gage #1	Gage #2	Correct Head Gage #1	Correct Head Gage #2	Quantity of Flow From Curve	Quantity of Flow Corrected
1	8:59	.520	.493				
		.520	.494				
		.517	.492				
		.520	.494				
		.520	.493				
		.520	.494				
		.519	.493				
		.527	.490				
	9:14	(.519)	(.494)	.479	.480	10.58	10.65

(Data from Elbow Gage)

Run No.	Time	Gage Readings (ft.) left (elbow)	Gage Readings (ft.) right (Pump)	Difference in Head
1	8:59	3.671	3.563	
		3.650	3.544	
		3.668	3.559	
		3.696	3.594	
		3.667	3.575	
		3.699	3.590	
		3.699	3.588	
		3.617	3.516	
	9:14	(3.467)	(3.429)	0.1047

(Data from Engine)

Run No.	Time	Counter Reading Initial	Counter Reading Final	Revolutions	Revolutions per Minute
1	8:59	22706			
	9:04				
	9:09				
	9:14		24554	1848	123

CALIBRATION OF 30" ELBOW
Summary data sheet

Data by Rheingans, Wiepking, and Kidder.

Date, December, 1919.

Run No.	Quantity of Flow From Curve (S.F.)	Quantity of Flow Corrected (S.F.)	Velocity (ft/sec)	Velocity Squared $(ft/sec)^2$	Reading Elbow Gage (ft)
1	6.42	6.49	1.321	1.750	.0391
2	6.80	6.87	1.399	1.960	.0533
3	7.17	7.24	1.473	2.175	.0563
4	10.58	10.65	2.168	4.71	.1047
5	9.66	9.73	1.981	3.94	.0760
6	9.14	9.21	1.875	3.52	.0752
7	7.43	7.50	1.528	2.34	.0562
8	8.37	8.44	1.719	2.95	.0745
9	12.36	12.43	2.534	6.42	.1120
10	12.83	12.90	2.625	6.90	.1250
11	13.45	13.52	2.756	7.60	.1460
12	14.00	14.07	2.865	8.21	.1395
13	13.45	13.52	2.756	7.60	11130
14	12.86	12.93	2.636	6.95	.1120
15	11.53	11.60	2.362	5.59	.1060
16	6.52	6.59	1.341	1.803	.0491
17	6.95	7.02	1.430	2.05	.0534
18	6.90	6.97	1.420	2.02	.0544
19	13.00	13.07	2.660	7.08	.1163
20	14.00	14.07	2.865	8.21	.1363
21	13.36	13.43	2.739	7.50	.1259
22	12.70	12.77	2.600	6.77	.1162
23	12.28	12.35	2.518	6.33	.0954
24	7.32	7.39	1.504	2.265	.0560
25	7.60	7.67	1.562	2.445	.0572
26	7.90	7.97	1.622	2.640	.0462
27	14.00	14.07	2.865	8.21	.1365
28	8.45	8.52	1.735	3.01	.0649
29	8.23	8.30	1.691	2.86	.0666
30	7.48	7.55	1.538	2.37	.0590
31	10.42	10.49	2.136	4.56	.1080
32	11.00	11.07	2.253	5.09	.1174
33	11.70	11.77	2.399	5.75	.1076
34	12.25	12.32	2.512	6.32	.1156
35	13.17	13.24	2.700	7.29	.1255
36	14.05	14.12	2.880	8.30	.1310
37	14.68	14.75	3.050	9.05	.1634
38	15.63	15.70	3.200	10.22	.1833
39	23.12	23.19	4.725	22.30	.2410
40	26.74	26.81	5.460	29.90	.2828

Calibration of 30" Elbow (Cont'd)
Summary Data Sheet

Data by Rheingans, Wiepking, and Kidder.

Date, December, 1919.

Run No.	Quantity of Flow: From Curve (S.F.)	Quantity of Flow: Corrected (S.F.)	Velocity (ft/sec)	Velocity Squared $(ft/sec)^2$	Reading Elbow Gage (ft)
41	25.83	25.90	5.28	27.90	.2676
42	27.67	27.74	5.65	32.00	.2919
43	30.30	30.37	6.19	38.30	.3260
44	32.72	32.79	6.68	44.70	.3665
45	32.36	32.43	6.61	43.70	.3774
			6.15		
46	30.10	30.17	5.48	37.80	.3122
47	26.84	26.91	5.00	30.10	.2703
48	24.50	24.57	4.49	25.05	.2495
49	21.96	22.03	3.925	20.20	.2320
50	19.21	19.28	6.59	15.40	.2010
51	32.30	32.37	6.59	43.50	.3270
52	31.79	31.86	6.495	42.20	.3640
53	31.01	31.08	6.34	40.20	.3480
54	30.53	30.60	6.23	38.90	.3330
55	29.42	29.49	6.01	36.10	.3120
56	28.39	28.46	5.80	33.60	.2970
57	23.62	23.69	4.83	23.40	.2560
58	21.62	21.69	4.42	19.60	.2410
59	17.70	17.77	3.62	13.15	.2330
60	15.90	15.97	3.254	10.60	.1940
61	14.40	14.47	2.946	8.70	.1470
62	13.64	13.71	2.795	7.82	.1300
63	13.28	13.36	2.721	7.40	.1530
64	11.66	11.73	2.390	5.71	.1380
65	10.90	10.97	2.235	5.00	.0940
66	9.63	9.70	1.976	3.91	.0700
67	12.48	12.55	2.560	6.55	.1170
68	14.30	14.37	2.925	8.58	.1440
69	16.17	16.24	3.100	11.00	.2200
70	17.42	17.49	3.580	12.83	.2360
71	17.58	17.65	3.600	12.95	.2410
72	19.70	19.77	4.030	16.20	.2580
73	19.25	19.32	3.940	15.55	.2620
74	23.60	23.67	4.830	23.30	.2390
75	25.22	25.29	5.150	26.60	.2820

Calibration of 30" Elbow (Cont'd)
Summary Data Sheet

Data by Rheingans, Wiepking, and Kidder.

Date, December, 1919.

Run No.	Quantity of Flow From Curve (S.F.)	Quantity of Flow Corrected (S.F.)	Velocity (ft/sec)	Velocity Squared $(ft/sec)^2$	Reading Elbow Gage (ft)
41	25.83	25.90	5.28	27.90	.2876
42	27.67	27.74	5.65	32.00	.2919
43	30.30	30.37	6.19	38.30	.3280
44	32.72	32.79	6.68	44.70	.3665
45	32.36	32.45	6.61	43.70	.3774
			6.15		
46	30.10	30.17	5.48	37.80	.3122
47	28.84	28.91	5.00	30.10	.2705
48	24.50	24.57	4.49	25.05	.2495
49	21.96	22.03	3.925	20.20	.2320
50	19.21	19.28	6.59	15.40	.2010
51	32.30	32.37	6.59	43.50	.3270
52	31.79	31.86	6.495	42.20	.3640
53	31.01	31.08	6.34	40.20	.3480
54	30.53	30.60	6.23	38.90	.3350
55	29.42	29.49	6.01	36.10	.3120
56	28.39	28.46	5.80	33.60	.2970
57	25.62	25.69	4.85	25.40	.2560
58	21.62	21.69	4.42	19.60	.2410
59	17.70	17.77	3.62	13.15	.2330
60	15.90	15.97	3.254	10.60	.1940
61	14.40	14.47	2.946	8.70	.1470
62	13.64	13.71	2.795	7.82	.1300
63	13.28	13.36	2.721	7.40	.1530
64	11.66	11.73	2.390	5.71	.1380
65	10.90	10.97	2.235	5.00	.0940
66	9.63	9.70	1.976	3.91	.0700
67	12.48	12.55	2.560	6.55	.1170
68	14.30	14.37	2.925	8.58	.1440
69	16.17	16.24	3.100	11.00	.2200
70	17.42	17.49	3.580	12.85	.2360
71	17.58	17.65	3.600	12.95	.2410
72	19.70	19.77	4.030	16.20	.2580
73	19.25	19.32	3.940	15.55	.2620
74	23.60	23.67	4.830	23.30	.2390
75	25.22	25.29	5.150	26.60	.2820

Calibration of 30" Elbow (Cont'd)
Summary Data Sheet

Data by Rheingans, Wiepking, and Kidder.

Date, December, 1919.

Run No.	Quantity of Flow: From Curve (S.F.)	Quantity of Flow: Corrected (S.F.)	Velocity (ft/sec)	Velocity Squared $(ft/sec)^2$	Reading Elbow Gage (ft)
76	26.27	26.34	5.36	28.80	.264
77	27.00	27.07	5.53	30.50	.273
78	28.36	28.43	5.80	33.60	.285
79	29.04	29.11	5.94	35.25	.304
80	30.01	30.08	6.13	37.60	.322
			3.50		
81	17.12	17.19	3.50	12.20	.164
82	13.67	13.74	2.80	7.82	.125
83	14.93	15.00	3.06	9.32	.135
84	16.20	16.27	3.31	11.00	.189
85	16.82	16.89	3.44	11.80	.196
86	17.06	17.13	3.49	12.20	.226
87	18.45	18.52	3.77	14.23	.232
88	19.00	19.07	3.88	15.10	.247
89	18.57	18.64	3.80	14.40	.237
90	18.80	18.87	3.84	14.78	.236
91	18.25	18.32	3.73	13.96	.231
92	17.31	17.38	3.54	12.56	.213
93	17.10	16.17	3.295	10.85	.196
94	17.08	17.15	3.496	12.22	.215
95	18.01	18.08	3.682	13.60	.235
96	18.45	18.52	3.770	14.23	.236
97	18.68	18.75	3.820	14.60	.233
98	17.90	17.97	3.661	13.41	.233
99	16.00	16.07	3.273	10.72	.172
100	17.68	17.75	36.18	13.08	.227

Calibration of 8" Elbow
(Horizontal #1)
Summary Data Sheet

Data by Rheingans, Wiepking, and Kidder.

Date, February, 1920.

Area of Crossection Elbow #1 = .3455 square feet.

Run No.	Quantity of Flow: From Curve (S.F.)	Quantity of Flow: Corrected (S.F.)	Velocity (ft/sec)	Velocity Squared $(ft/sec)^2$	Reading Elbow Gage (ft)
1	7.829	7.843	22.7	515	3.979
2	7.447	7.461	21.6	467	3.682
3	7.160	7.174	20.8	430	3.366
4	6.950	6.964	20.2	406	3.213
5	6.592	6.606	19.15	366	2.920
6	6.337	6.351	18.40	339	2.636
7	6.038	6.052	17.55	307	2.415
8	5.501	5.515	16.00	255	2.005
9	5.033	5.047	14.60	212.5	1.704
10	4.531	4.545	13.13	172.0	1.380
11	4.125	4.139	11.96	143.0	1.128
12	3.814	3.828	11.10	122.0	0.975
13	3.468	3.482	10.10	102.0	0.798
14	3.134	3.148	9.12	83.0	0.668
15	2.672	2.686	7.78	60.4	0.479
			6.92		
16	2.375	2.389	6.92	47.9	0.386
17	1.626	1.640	4.75	22.5	0.182
18	0.754	0.768	2.12	4.95	0.038
19	7.943	7.957	23.00	530	4.030
20	7.878	7.892	22.80	520	3.951
			22.29		
21	7.653	7.667	22.20	492	3.781
22	7.235	7.249	21.00	440	3.354
23	6.934	6.948	20.10	403	3.141
24	6.562	6.576	19.03	361	2.744
25	6.138	6.152	17.85	318	2.452
26	5.798	5.812	16.95	284	2.210
27	5.501	5.515	16.00	255	19.80
28	5.099	5.113	14.80	219	1.727
29	4.590	4.604	13.35	178	1.367
30	4.304	4.318	12.50	156	1.211
31	4.070	4.084	11.80	140	1.080
32	3.769	3.783	10.97	120	0.930
33	3.456	3.470	10.02	100.5	0.787
34	3.145	3.159	9.15	83.2	0.650
35	2.855	2.869	8.30	69.0	0.534
36	2.491	2.505	7.26	52.7	0.413
37	2.078	2.092	6.05	36.6	0.287

Calibration Of 8" Elbow
(Vertical Gage #2)
Summary Data Sheet

Data By Rheingans, Weipking, and Kidder.

Date, February, 1920.

Area Crossection Elbow = .342 square feet.

Run No.	Quantity of Flow: From C Curve (S.F.)	Quantity of Flow: Corrected (S.F.)	Velocity (ft/sec)	Velocity Squared (ft/sec)^2	Reading Elbow Gage (ft)
1	7.829	7.843	22.95	525	4.280
2	7.447	7.461	21.85	477	3.934
3	7.160	7.174	21.00	440	3.618
4	6.950	6.964	20.40	415	3.470
5	6.592	6.606	19.35	375	3.042
6	6.337	6.351	18.60	345	2.815
7	6.038	6.052	17.70	313	2.563
8	5.501	5.515	16.15	260	2.182
9	5.033	5.047	14.74	216	1.802
10	4.531	4.545	13.30	176	1.445
11	4.125	4.139	12.10	146	1.218
12	3.814	3.828	11.20	125	1.040
13	3.468	3.482	10.20	104	0.863
14	3.134	3.148	9.21	84.8	0.713
15	2.672	2.686	7.86	61.8	0.515
				49.0	
16	2.375	2.389	7.00	49.0	0.415
17	1.626	1.640	4.80	23.0	0.197
18	0.754	0.768	2.25	5.05	0.052
19	7.943	7.967	23.30	540	4.302
20	7.878	7.892	23.05	530	4.252
21	7.653	7.667	22.40	502	4.007
22	7.235	7.249	21.20	449	3.594
23	6.934	6.948	20.30	411	3;288
24	6.562	6.576	19.22	370	2.900
25	6.138	6.152	18.02	325	2.630
26	5.798	5.812	17.02	290	2.345
27	5.501	5.515	16.15	260	2.128
28	5.099	5.113	15.00	225	1.918
29	4.590	4.604	13.50	182	1.460
30	4.304	4.318	12.65	160	1.300
31	4.070	4.084	11.95	142	1.150
32	3.769	3.783	11.08	122	1.014
33	3.456	3.470	10.15	102.5	0.842
34	3.145	3.159	9.24	85.0	0.706
35	2.855	2.869	8.40	70.2	0.584
36	2.491	2.505	7.33	53.6	0.450
37	2.078	2.092	6.11	37.4	0.315
38	1.648	1.662	4.86	23.6	0.205

Calibration Of 6" Elbow
Summary Data Sheet

Data by Rheingans, wiepking, and Kidder.

Date, February, 1920.

Area Crossection Pipe = .2006 square feet.

Run No.	Quantity of Flow From Curve (S.F.)	Quantity of Flow Corrected (S.F.)	Velocity (ft/sec)	Velocity Squared $(ft/sec)^2$	Reading Elbow Gage (ft)
1	.4048	.4048	3.38	11.42	.065
2	.4439	.4439	3.87	14.97	.083
3	.4547	.4547	4.01	16.10	.088
4	.4759	.4759	4.30	18.40	.115
5	.4930	.4930	4.51	20.40	.152
6	.5085	.5085	4.71	22.20	.163
7	.5242	.5242	4.93	24.20	.174
8	.5334	.5334	5.05	25.50	.185
9	.5619	.5619	5.45	29.70	.214
10	.5709	.5709	5.60	31.10	.236
11	.5763	.5763	5.65	32.0	.236
12	.5837	.5837	5.75	33.0	.252
13	.6043	.6043	6.05	36.5	.272
14	.6211	.6211	6.30	39.6	.307
15	.6389	.6389	6.57	43.1	.325
16	.6517	.6517	6.77	45.7	.356
17	.6784	.6785	7.19	51.6	.398
18	.7017	.7017	7.56	57.0	.424
19	.7191	.7191	7.74	60.0	.442
20	.7340	.7340	8.09	65.1	.471
21	.7473	.7473	8.29	68.6	.469
22	.7632	.7632	8.55	73.0	.494
23	.7672	.7672	8.63	74.3	.524
24	.7870	.7870	8.96	80.0	.548
25	.7907	.7907	9.03	81.2	.565
26	.8014	.8014	9.20	84.2	.595
27	.8133	.8133	9.40	88.0	.615
28	.8373	.8373	9.82	96.2	.644
29	.8031	.8031	9.24	85.0	.596
30	.8169	.8169	9.45	89.2	.625
31	.8221	.8221	9.55	91.0	.621
32	.8276	.8276	9.65	92.9	.628
33	.8324	.8324	9.73	94.5	.640
34	.8478	.8478	10.00	100.0	.688
35	.8484	.8484	10.01	100.1	.688

Calculation of 6" Elbow
Summary Data Sheet

Data by Rheingans, Wiepking, and Kidder.

Date, February, 1920.

Area Crossection Pipe = .2006 square feet.

Run No.	Head on Weir (ft)	Quantity of Flow (S.F.)	Velocity (ft/sec)	Velocity Squared (ft/sec)^2	Reading Elbow Gage
36	.8623	2.060	10.26	105.0	.719
37	.8667	2.076	10.33	106.2	.738
38	.8713	2.080	10.37	107.0	.750
39	.8762	2.110	10.51	110.3	.764
40	.8794	2.120	10.58	111.7	.803
41	.8714	2.093	10.42	108.3	.752
42	.8796	2.122	10.60	112.0	.773
43	.8855	2.144	10.70	114.1	.780
44	.8838	2.138	10.63	113.0	.782
45	.8865	2.148	10.71	114.3	.749
46	.8867	2.148	10.71	114.3	.746
47	.8899	2.160	10.77	115.9	.753
48	.8894	2.157	10.72	115.0	.800
49	.8907	2.162	10.80	116.2	.796
50	.8928	2.170	10.82	117.0	.804
51	.8992	2.190	10.91	119.0	.833
52	.8804	2.123	10.60	112.0	.776
53	.8786	2.120	10.59	111.5	.782
54	.8721	2.094	10.45	109.0	.766
55	.8633	2.067	10.31	106.2	.730
56	.8530	2.028	10.11	102.0	.707
57	.8425	1.992	9.93	98.2	.710
58	.8405	1.983	9.89	97.4	.673
59	.8295	1.946	9.70	93.9	.642
60	.8200	1.912	9.53	90.8	.627
61	.8111	1.880	9.36	87.7	.613
62	.8051	1.862	9.28	86.0	.605
63	.7985	1.838	9.15	83.6	.571
64	.7912	1.811	9.04	81.4	.566
65	.7809	1.780	8.86	78.5	.544
66	.7771	1.766	8.80	77.1	.544
67	.7662	1.730	8.61	74.0	.515
68	.7599	1.710	8.52	72.4	.503
69	.7496	1.673	8.34	69.3	.489
70	.7231	1.587	7.91	62.4	.427

(Second Setting)

Calibration of 4" Elbow
Summary Data Sheet

Data by Rheingans, Wiepking, and Kidder.

Date, February, 1920.

Area Crossection Pipe = .0884 square feet.

Run No.	Head on Weir (S.F)	Quantity of Flow (S.F.)	Velocity (ft/sec)	Velocity Squared $(ft/sec)^2$	Geading Elbow Gage (ft)
1	.6413	1.625	18.4	340	3.277
2	.6039	1.480	16.74	280	27.47
3	.5750	1.375	15.60	243	2.395
4	.5504	1.290	14.60	214	2.075
5	.5420	1.260	14.25	204	1.866
6	.5059	1.146	12.85	165	1.660
7	.4710	1.025	11.60	134	1.348
8	.4252	0.877	9.92	99	1.002
9	3808	0.745	8.44	71.2	0.733
10	.3608	0.690	7.80	61.0	0.616
11	.3338	0.615	6.96	48.5	0.500
12	.3059	0.540	6.11	37.5	0.385
13	.2453	0.395	4.47	20.0	0.223
14	.0608	0.065	0.74	0.5	0.023
15	.1561	0.205	2.32	5.4	0.056
16	.2349	0.370	4.20	17.6	0.187
17	.3059	0.541	6.13	37.6	0.384
18	.3490	0.655	7.41	55.0	0.570
19	.3986	0.795	9.00	81.0	0.844
20	.4367	0.910	10.30	106.0	10.87
21	.4675	1.010	11.4	130	1.266
22	.4897	1.075	12.2	148	1.478
23	.5215	1.190	13.5	182	1.785
24	.5415	1.255	14.2	202	1.996
25	.5603	1.325	15.0	225	2.219
26	.5730	1.370	15.5	240	2.349
27	.5912	1.435	16.3	265	2.607
28	.6152	1.525	17.3	298	2.890
29	.6272	1.570	17.8	316	3.119
30	.6524	1.670	18.9	357	3.427

Calibration of 4" Elbow
(First Setting)
Summary Data Sheet

Data by Rheingans, Wiepking, and Kidder.

Date, February, 1920.

Area Crossection Pipe = 0.884

Run No.	Head on Weir (ft)	Quantity of Flow (S.F.)	Velocity (ft/sec)	Velocity Squared (ft/sec)^2	Reading Elbow Gage (ft)
1	.2030	.252	2.85	8.10	.030
2	.2286	.297	3.35	11.20	.044
3	.2498	.337	3.81	14.50	.036
4	#2646	.367	4.15	17.20	.058
5	.2749	.388	4.38	19.20	.081
6	.2983	.437	4.94	24.4	.114
7	.2991	.439	4.96	24.6	.124
8	.3091	.460	5.20	27.0	.144
9	.3222	.490	5.54	30.6	.161
10	.3345	.516	5.84	34.0	.193
11	.3487	.550	6.22	38.6	.202
12	.3512	.554	6.26	39.2	.218
13	.3737	.608	6.88	47.2	.229
14	.3845	.631	7.15	51.0	.264
15	.3949	.657	7.44	55.1	.283
16	.4183	.713	8.06	65.0	.316
17	.4471	.785	8.89	78.6	.323
18	.4665	.834	9.44	89.0	.409
19	.4934	.905	10.24	102.5	.411
20	.5145	.953	10.80	116.0	.450
21	.5377	1.030	11.62	135.5	.518
22	.5852	1.162	13.14	173.5	.618
23	.6088	1.228	13.88	192.0	.916
24	.2953	.432	4.87	23.7	.125
25	.2700	.378	4.25	18.0	.099
26	.2410	.320	3.62	13.1	.074
27	.2149	272	3.08	9.42	.024
28	.2421	.323	3.65	13.35	.095
29	.2542	.346	3.91	15.30	.104
30	.2877	.414	4.68	21.90	.126

Calibration of 4" Elbow
(First Setting)
Summary Data Sheet

Data by Rheingans, Wiepking, and Kidder.

Date, February, 1920.

Area Crossection Pipe = .0884 square feet.

Run No.	Head on Wier (ft)	Quantity of Flow (S.F.)	Velocity (ft/sec)	Velocity Squared $(ft/sec)^2$	Reading Elbow Gage (ft)
31	.3430	.537	6.07	36.945.5	.218
32	.3690	.597	6.75	45.5	.256
33	.3765	.615	6.95	48.4	.269
34	.4046	.680	7.69	59.0	.336
35	.4149	.705	7.97	63.4	.350
36	.4278	.737	8.34	69.2	.334
37	.4490	.790	8.94	79.9	.358
38	.4581	.815	9.23	85.0	.372
39	.4697	.843	9.54	90.9	.392
40	.4900	.898	10.18	103.0	.425
41	.5079	.947	10.72	115.0	.529
42	.5237	.990	11.20	125.0	.551
43	.5439	1.046	11.82	140.0	.608
44	.6063	1.222	13.82	191.0	.847
45	.6518	1.360	15.39	236.0	1.021
46	.7852	1.793	20.3	411.0	2.605
47	.6470	1.343	15.2	231.0	1.348
48	.6019	1.210	13.69	187.0	1.000
49	.5485	1.058	11.98	142.5	.716
50	.4899	.898	10.18	103.0	.601
51	.4819	.876	9.91	98.0	.560
52	4669	.837	9.46	89.5	.461
53	.4410	.771	8.73	76.0	.377
54	.4137	.702	7.94	63.0	.318
55	.3977	.666	7.54	56.8	.299
56	.3793	.618	7.00	49.0	.257
57	.3537	.560	6.34	40.1	.230
58	.3358	.520	5.88	34.5	.192
59	.3143	.470	5.32	28.3	.162
60	.2887	.417	4.72	22.2	.126

PERCENT VARIATION IN VELOCITY READINGS

4" Setting #2

Velocity Squared		Velocity		Correction in Velocity		Percent Correction	
Observed	From Curve	Observed	From Curve	+	−	+	−
5.5	5.5	2.34	2.34		0		0
17.5	18.5	4.18	4.30	.12		2.8	
20.0	22.0	4.46	4.70	.24		5.4	
37.5	39.0	6.12	6.24	.12		1.9	
37.5	39.0	6.12	6.24	.12		1.9	
48.5	50.0	6.95	7.06	.11		1.6	
55.0	57.5	7.40	7.75	.17		2.3	
61.0	62.0	7.80	7.86	.06		.77	
71.0	73.5	8.41	8.57	.16		1.9	
81.0	85.0	9.00	9.20	.20		2.2	
99.5	101.0	9.95	10.05	.10		1.0	
106.0	109.0	10.3	10.45	.15		1.5	
130.0	128.0	11.4	11.30		.10		.87
134.0	136.0	11.6	11.65	.05		.43	
148.0	149.0	12.15	12.20	.05		.40	
165.0	168.0	12.85	12.95	.10		.78	
181.0	182.0	13.45	13.50		.05		.38
202.0	202.0	14.25	14.25	0		0	
210.0	214.0	14.50	14.60		.10		.67
225.0	225.0	15.00	15.00	0		0	
238.0	240.0	15.4	15.50		.10		.65
243.0	243.0	15.6	15.60	0		0	
264.5	264.0	16.3	16.30	0		0	
279.0	280.0	16.7	16.75		.05		.30
294.0	298.0	17.1	17.24		.15		.87
336.0	336.0	18.3	18.30	0		0	
240.0	333.0	18.4	18.20		.20		1.10
357.0	349.0	18.9	18.70		.20		1.10

PERCENT VARIATION IN VELOCITY READINGS

4" Setting #1

Velocity Squared Observed	Velocity Squared From Curve	Velocity Observed	Velocity From Curve	Correction in Velocity +	Correction in Velocity −	Percent Correction +	Percent Correction −
6	8	2.45	2.82	.37		15.1	
9	5	3.00	2.23		.77		25.6
8	6	2.28	2.45		.37		13.1
11	9	3.31	3.00		.31		9.4
17	12	4.12	3.46		.66		16.0
13	14	3.60	3.74	.14		3.9	
19	16	4.35	4.00		.35		8.1
13	18	3.60	4.25	.65		18.0	
15	19	3.86	4.35	.49		12.7	
18	19	4.25	4.35	.10		2.3	
22	24	4.70	4.90	.20		4.25	
22	24	4.70	4.90	.20		4.25	
24	24	4.90	4.90	0		0	
24	25	4.90	5.00	.10		2.04	
22	25	4.70	5.00	.30		6.4	
27	28	5.2	5.30	.10		1.9	
28	31	5.3	5.55	.25		4.7	
30	31	5.47	5.55	.08		1.46	
34	37	5.83	6.08	.25		4.3	
39	39	6.25	6.25	0		0	
37	42	6.08	6.47	.35		5.7	
39	42	6.25	6.47	.22		3.5	
40	45	6.32	6.70	.38		6.0	
47	45	6.85	6.70		.15		2.2
45	49	6.70	7.00	.30		4.5	
49	49	7.0	7.00	0		0	
49	52	7.0	7.20	.20		2.8	
51	51	7.14	7.14	0		0	
55	55	7.40	7.40	0		0	
57	58	7.55	7.60	.05		.66	

PERCENT VARIATION IN VELOCITY READINGS

4" Setting #1

Velocity Squared Observed	Velocity Squared From Curve	Velocity Observed	Velocity From Curve	Correction in Velocity		Percent Correction	
6	8	2.45	2.82	.37		15.1	
9	5	3.00	2.23		.77		25.6
8	6	2.83	2.45		.37		13.1
11	9	3.31	3.00		.31		9.4
17	12	4.12	3.46		.66		16.0
13	14	3.60	3.74	.14		3.9	
19	16	4.35	4.00		.35		8.1
13	18	3.60	4.25	.65		18.0	
15	19	3.86	4.35	.49		12.7	
18	19	4.25	4.35	.10		2.3	
22	24	4.70	4.90	.20		4.25	
22	24	4.70	4.90	.20		4.25	
24	24	4.90	4.90	0		0	
24	25	4.90	5.00	.10		2.04	
22	25	4.70	5.00	.30		6.4	
27	28	5.2	5.30	.10		1.9	
28	31	5.3	5.55	.25		4.7	
30	31	5.47	5.55	.08		1.46	
34	37	5.83	6.08	.25		4.3	
39	39	6.25	6.25	0		0	
37	42	6.08	6.47	.35		5.7	
39	42	6.25	6.47	.22		3.5	
40	45	6.32	6.70	.38		6.0	
47	45	6.85	6.70		.15		2.2
45	49	6.70	7.00	.30		4.5	
49	49	7.0	7.00	0		0	
49	52	7.0	7.20	.20		2.8	
51	51	7.14	7.14	0		0	
55	55	7.40	7.40	0		0	
57	58	7.55	7.60	.05		.66	

PERCENT VARIATION IN VELOCITY READINGS

4" Setting #1

Velocity Squared Observed	Velocity Squared From Curve	Velocity Obs.	Velocity From Curve	Correction in Velocity		Percent Correction	
63	62	7.93	7.86		.07		.89
65	62	8.05	7.86		.19		2.3
69	65	7.67	8.05	.38		5.0	
64	68	8.00	8.25	.25		3.1	
69	65	8.30	7.67		.63		8.2
78	63	8.88	7.94		.94		10.7
80	70	8.93	8.35		.58		6.5
76	74	8.70	8.60		.10		1.1
85	74	9.20	8.60		.60		6.5
89	79	9.42	8.88		.54		5.7
91	77	9.53	8.75		.78		8.2
89	89	9.42	9.42		0		0
102	80	10.10	8.94		1.06		10.5
103	82	10.15	9.05		1.10		10.8
99	99	9.94	9.94		0		0
116	89	10.75	9.42		1.33		12.4
115	103	10.70	10.15		.55		5.1
98	109	9.90	10.45	.55		5.5	
104	117	10.20	10.80	.60		5.9	
125	107	11.20	10.35	.15		1.3	
140	118	11.80	10.85	.05		0.4	
143	140	11.95	11.80		.15		1.3
172	110	13.10	10.50		2.60		2.0
191	165	13.80	12.80		1.00		0.7
192	180	13.85	13.40		.45		3.3
187	195	13.65	13.95	.30		2.2	
236	200	15.40	14.10		1.30		8.4

PERCENT VARIATION IN VELOCITY READINGS

6" Setting

Velocity Squared		Velocity		Correction in Velocity		Percent Correction	
Observed	From Curve	Observed	From Curve	+	−	+	−
11.5	9.5	3.39	3.36		.03		0.9
11.0	10.0	3.32	3.16		.16		4.8
25.0	12.0	3.87	3.46		.41		10.6
16.0	12.5	4.00	3.54		.46		11.5
18.5	16.5	4.30	4.05		.25		5.8
20.5	21.5	4.52	4.64	.12		2.7	
22.0	23.5	4.70	4.85	.15		3.2	
24.0	25.0	4.90	5.00	.10		2.0	
25.5	26.5	5.05	5.15	.10		2.0	
29.0	27.0	5.38	5.20		.18		3.3
29.5	30.5	5.44	5.52	.08		1.5	
33.0	30.5	5.75	5.51		.24		4.2
31.0	34.0	5.56	5.83	.27		4.8	
32.0	34.0	5.65	5.83	.18		3.2	
36.5	39.0	6.05	6.25	.20		3.3	
				.34			
39.5	44.0	6.29	6.63	.34		5.4	
42.0	42.5	6.47	6.50	.03		0.5	
43.0	46.5	6.55	6.78	.23		3.5	
45.5	48.0	6.75	6.92	.17		2.5	
53.5	52.5	7.30	7.25		.05		0.7
51.5	57.0	7.17	7.55	.38		5.3	
57.0	61.0	7.55	7.80	.25		3.3	
60.0	63.5	7.75	7.96	.21		2.7	
62.5	61.5	7.90	7.85		.05		0.6
65.0	67.5	8.05	8.20	.15		1.9	
68.5	67.5	8.27	8.20		.07		0.8
69.5	70.0	8.33	8.34	.02		0.2	
73.0	81.0	8.55	8.41		.14		1.6
72.5	72.5	8.50	8.50		0		
74.0	74.0	8.60	8.60		0		
77.5	77.5	8.80	8.80		0		
72.0	73.5	8.50	8.59	.09		1.1	
80.0	78.0	8.95	8.10		.85		0.9
119.0	120.0	10.90	10.95	.05		0.5	
114.5	107.5	10.70	10.35		.35		3.3
114.5	108.0	10.70	10.40		.30		2.8
116.0	108.5	10.80	10.40		.40		3.7

PERCENT VARIATION IN VELOCITY READINGS

6" Setting

Velocity Squared		Velocity		Correction in Velocity		Percent Correction	
Observed	From Curve	Observed	From Curve	+	—	+	—
81.0	81.0	9.00	9.00	0	0	0	0
81.5	81.5	9.01	9.01	0	0	0	0
83.5	82.5	9.13	9.08		.06		.05
84.0	84.0	9.16	9.16		0		
85.0	86.0	9.20	9.26	.06		.07	
86.0	87.0	9.26	9.31	.05		.05	
88.0	88.0	9.37	9.37	0			
88.0	88.0	9.37	9.37	0			
89.0	89.0	9.43	9.47	.04		.04	
90.0	91.0	9.47	9.54	.07		.07	
91.0	91.0	9.54	9.54	0			
93.0	90.5	9.64	9.50		.14		1.4
94.0	93.0	9.70	9.64		.06		0.6
94.5	93.5	9.71	9.66		.05		0.5
96.0	93.0	9.78	9.64		.14		1.4
97.5	97.5	9.86	9.86		0		
98.5	98.5	9.90	9.90		0		
100.0	98.0	10.0	9.90		.10		1.0
100.0	99.0	10.0	9.95		.05		0.5
98.0	101.0	9.9	10.05	.15		1.50	
102.0	102.0	10.1	10.1	0			
105.0	104.0	10.25	10.2		.05		0.5
106.0	105.0	10.30	10.25		.05		0.5
106.0	106.0	10.30	10.3		0		
107.0	108.0	10.35	10.4	.05		.05	
108.0	108.0	10.40	10.4	0			
109.0	110.0	10.45	10.45	0			
110.0	110.0	10.50	10.5	0			
112.0	112.0	10.60	10.6	0			
112.0	111.5	10.60	10.55		.05		0.5
111.5	113.0	10.55	10.6	.05		.05	
113.0	113.0	10.60	10.6	0			
114.0	113.0	10.65	10.6		.05		0.5
115.0	115.5	10.70	10.75	.05		.05	
111.5	115.5	10.55	10.75	.20		.20	
116.0	115.0	10.75	10.70		.05		0.5
117.0	116.0	10.80	10.70		.05		0.5

PERCENT VARIATION IN VELOCITY READINGS

8" Elbow #1

Velocity Squared Observed	Velocity Squared From Curve	Velocity Observed	Velocity From Curve	Correction in Velocity +	Correction in Velocity −	Percent correction +	Percent correction −
5.0	5.0	2.24	2.24	0		0	
22.0	24.0	4.70	4.90	.20		4.2	
37.0	37.0	6.07	6.07	0		0	
48.0	50.0	6.91	7.06	.15		2.2	
52.0	54.0	7.20	7.35	.15		2.1	
61.0	61.5	7.80	7.85	.05		.6	
69.0	69.0	8.30	8.30	0		0	
83.0	84.0	9.10	9.15	.05		.5	
83.0	86.0	9.10	9.25	.15		1.6	
101.0	101.5	10.05	10.05	0		0	
102.0	102	10.10	10.10	0		0	
120.0	120	10.95	10.95	0		0	
123.0	125	11.10	11.20	.10		.9	
139.5	140	11.80	11.80		0		0
143.0	146	11.95	12.10	.15		1.2	
156.0	156	12.50	12.50	0		0	
178.0	177	13.35	13.30		.05		.4
172.0	178	13.10	13.35	.25		1.9	
212.0	219	14.55	14.80	.25		1.7	
219.0	223	14.80	14.95	.15		1.0	
253	253	15.90	15.90	0		0	
253	258	15.90	16.07	.17		1.1	
284	285	16.80	16.90	.10		.6	
307	312	17.50	17.70	.20		1.1	
318	316	17.80	17.75		.05		.3
339	341	18.35	18.50	.15		.8	
360.5	355	19.00	18.80		0.20		1.0
366	376	19.15	19.40	.25		1.3	
403	405	20.05	20.10	.05		.3	
406	414	20.15	20.30	.15		.7	
430	435	20.80	20.85	.05		.3	
440	432	20.95	20.80		.15		.7
467	474	21.60	21.70	.10		.5	
492	488	22.20	22.10		.10		.5
520	510	22.80	22.60		.20		.9
510	513	22.60	22.60		0		0

PERCENT VARIATION IN VELOCITY READINGS

8" Elbow #2

Velocity Observed	Velocity From Curve	Velocity Squared Observed	Velocity Squared From Curve	Correction in Velocity +	Correction in Velocity —	Percent Correction +	Percent Correction —
6,0	6.0	2.24	2.44	.20		9.0	
23.0	25.0	4.80	5.00	.20		4.2	
37.	38.0	6.08	6.15	.07		1.1	
49.0	51.0	7.00	7.14	.14		2.0	
53.0	55.0	7.27	7.40	.13		1.8	
61.0	61.5	7.80	7.83	.03		.4	
70.0	71.5	8.36	8.45	.09		1.1	
84.0	87.0	9.10	9.31	.21		2.3	
85.0	86.0	9.20	9.10		.10		1.10
101.0	101.0	10.05	10.05		0		0
		10.20					
104	106	20.20	10.30	.10		.98	
122	123	11.10	11.10	.05		.45	
125	127	11.20	11.25	.05		.45	
142	141	11.90	11.88		.02		.17
148	148	12.10	12.15	.05		.40	
160	160	12.65	12.65	0		0	
176	176.5	13.25	13.30	.05		.38	
182	179	13.50	13.40		.10		.75
216	220	14.70	14.80	.10		.68	
225	235	15.00	15.30	.30		2.00	
260	260	16.10	16.10	0		0	
260	267	16.10	16.30	.20		1.20	
290	287	17.00	16.95		.05		.29
313	314	17.70	17.75	.05		.28	
325	322	18.00	17.95		.05		.27
345	345	18.55	18.55	0		0	
370	356	18.85	19.20		.35		1.80
375	374	19.30	19.30	0		0	
411	403	20.20	20.05		.15		.74
415	425	20.40	20.60	.20		1.10	
440	443	20.95	21.00	.05		.24	
449	441	21.20	21.00		.20		.94
477	483	21.80	21.90	.10		.45	
503	492	22.40	22.20		.20		.90

TABLE OF VALUES OF Q FROM VALUES OF h

As Derived from Straight Line Relation between h and v^2

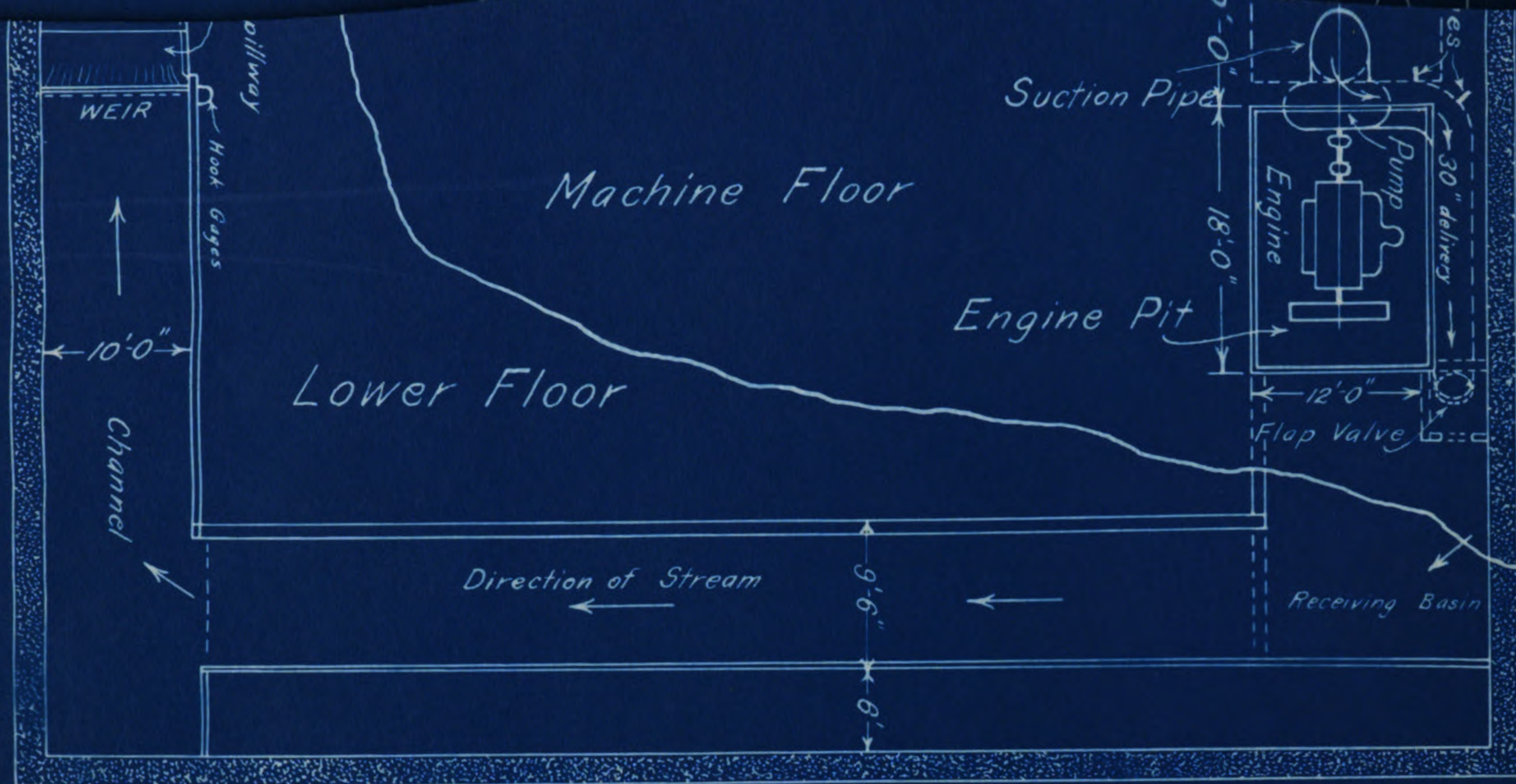
6" Elbow $Q = 2.405\sqrt{h}$		8" Elbow #1 $Q = 3.80\sqrt{h}$		8" Elbow #2 $Q = 3.92\sqrt{h}$	
h	Q	h	Q	h	Q
.1	.761	.50	2.60	.50	2.77
.2	1.075	1.00	3.80	1.00	3.92
.3	1.315	1.50	4.65	1.50	4.80
.4	1.520	2.00	5.36	2.00	5.54
.5	1.700	2.50	6.00	2.50	6.20
.6	1.860	3.00	6.56	3.00	6.79
.7	2.010	3.50	7.10	3.50	7.33
.8	2.130	4.00	7.60	4.00	7.84
.9	2.280	4.50	8.05	4.50	8.32
1.0	2.405	5.00	8.49	5.00	8.76

4" Elbow, Setting #1
$Q = 1.258\sqrt{h}$

h	Q
.1	.398
.2	.562
.3	.688
.4	.795
.5	.889
.6	.975
.7	1.051
.8	1.123
.9	1.191
1.0	1.258
1.2	1.379
1.4	1.490

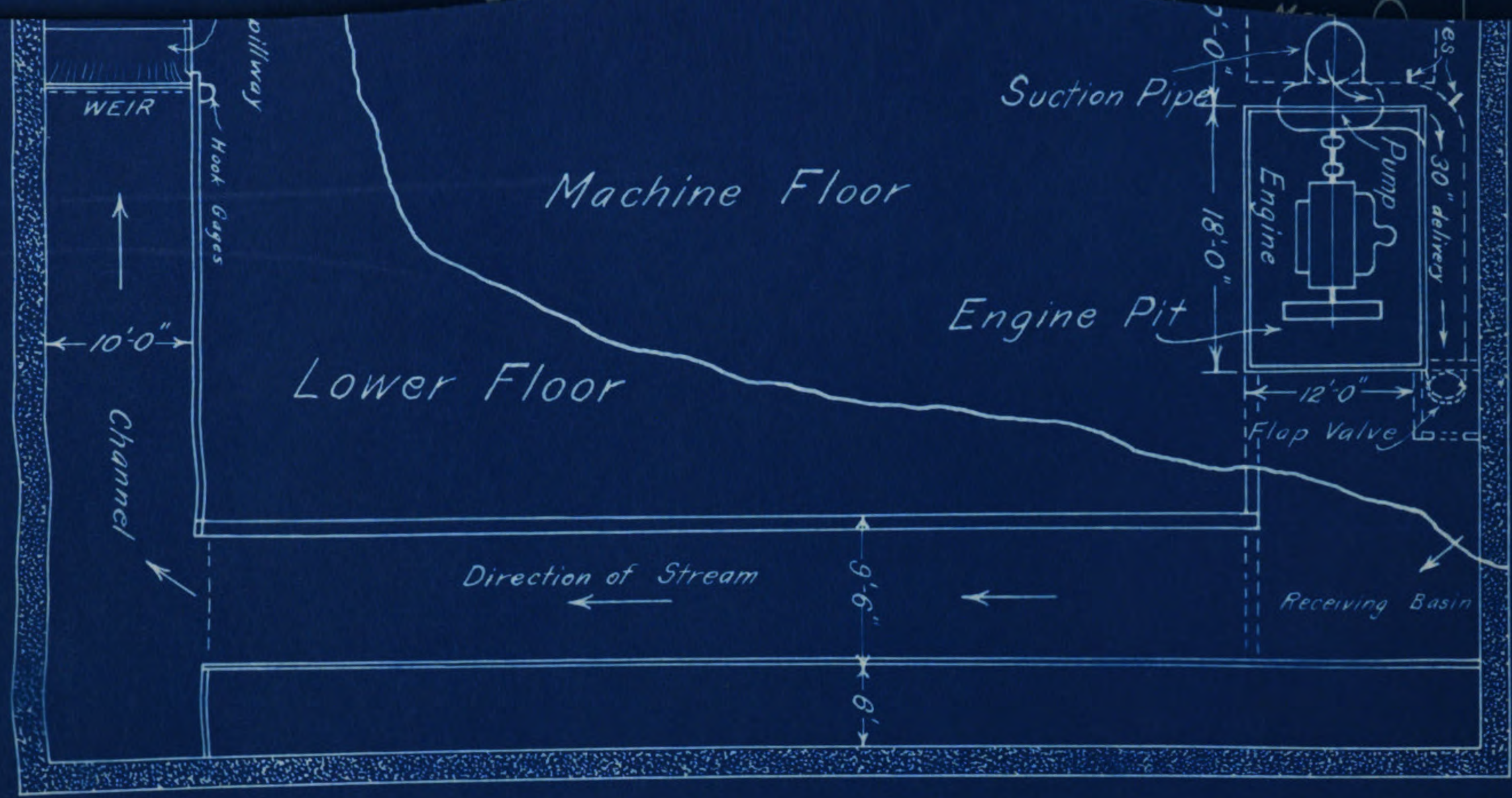
4" Elbow, Setting #2
$Q = .890\sqrt{h}$

h	Q
.25	.445
.50	.629
.75	.770
1100	.890
1.25	.996
1.50	1.090
1.75	1.180
2.00	1.260
2.25	1.338
2.50	1.407
2.75	1.475
3.00	1.542
3.25	1.605
3.50	1.665



Plan of Hydraulic Laboratory

showing



Plan of Hydraulic Laboratory

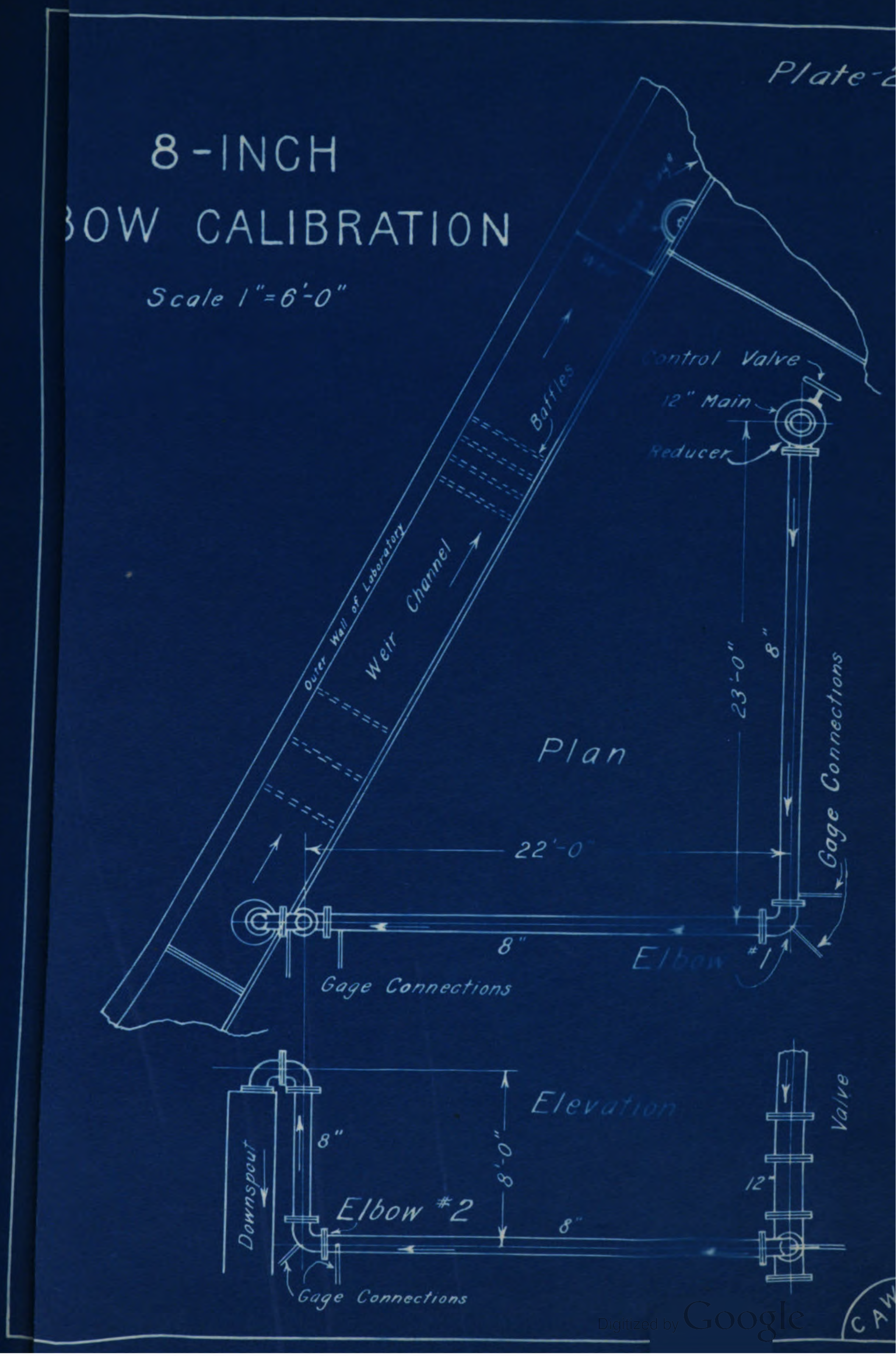
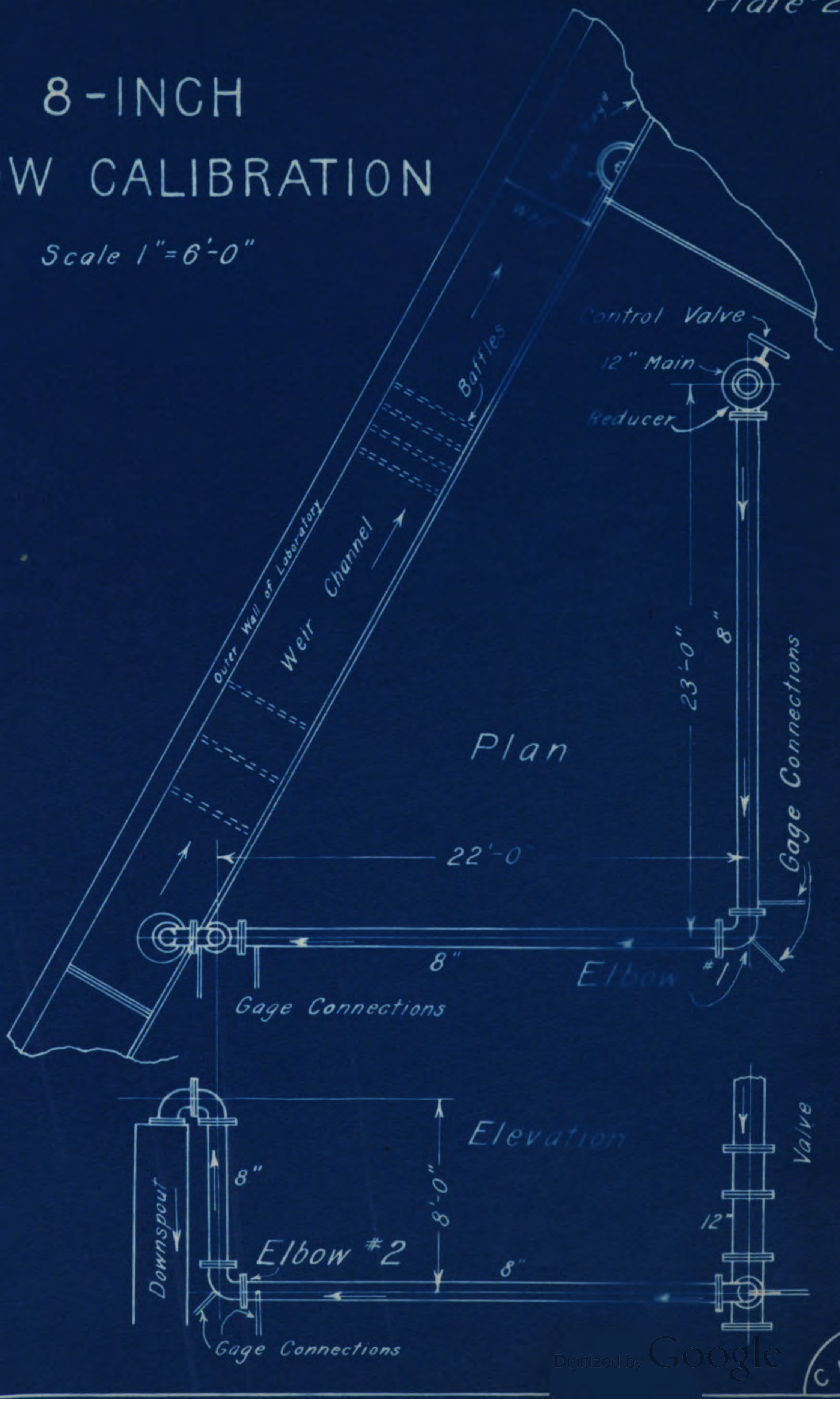


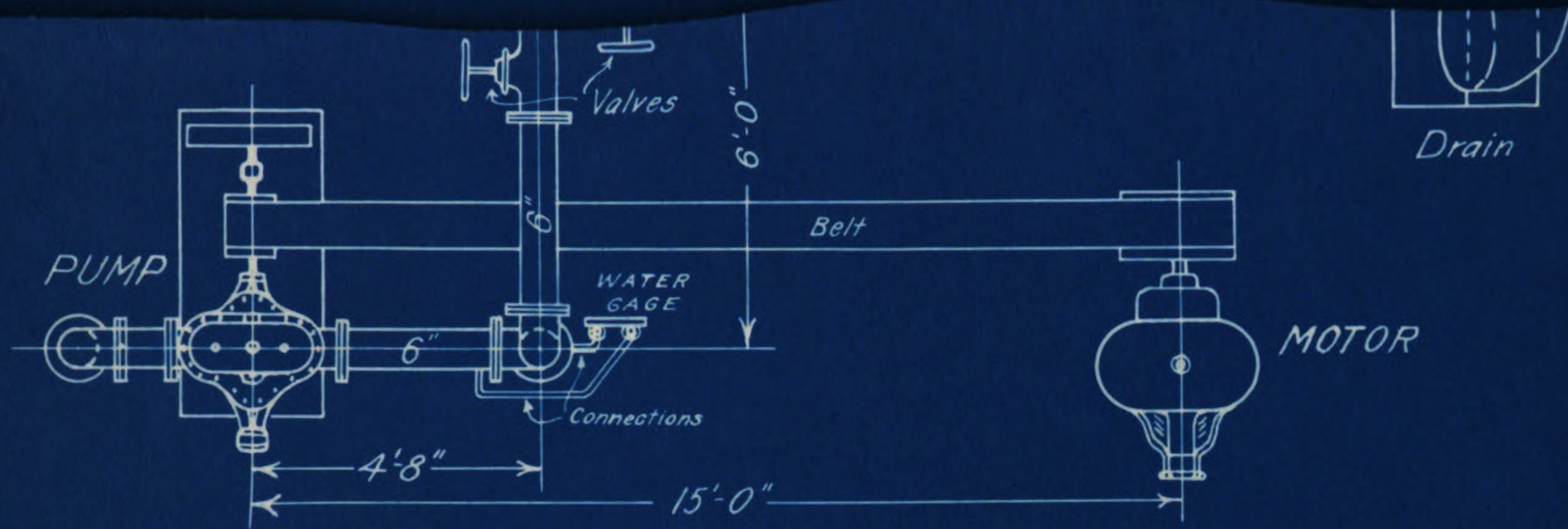
Plate-2
8-INCH
BOW CALIBRATION
Scale 1"=6'-0"
Control Valve
12" Main
Reducer
Baffles
Outer Wall of Laboratory
Weir Channel
Plan
23'-0"
8"
Gage Connections
22'-0"
8"
Elbow #1
Gage Connections
Elevation
8"
8'-0"
Downspout
Elbow #2
8"
Valve
12"
Gage Connections

Plate-2

8-INCH
BOW CALIBRATION

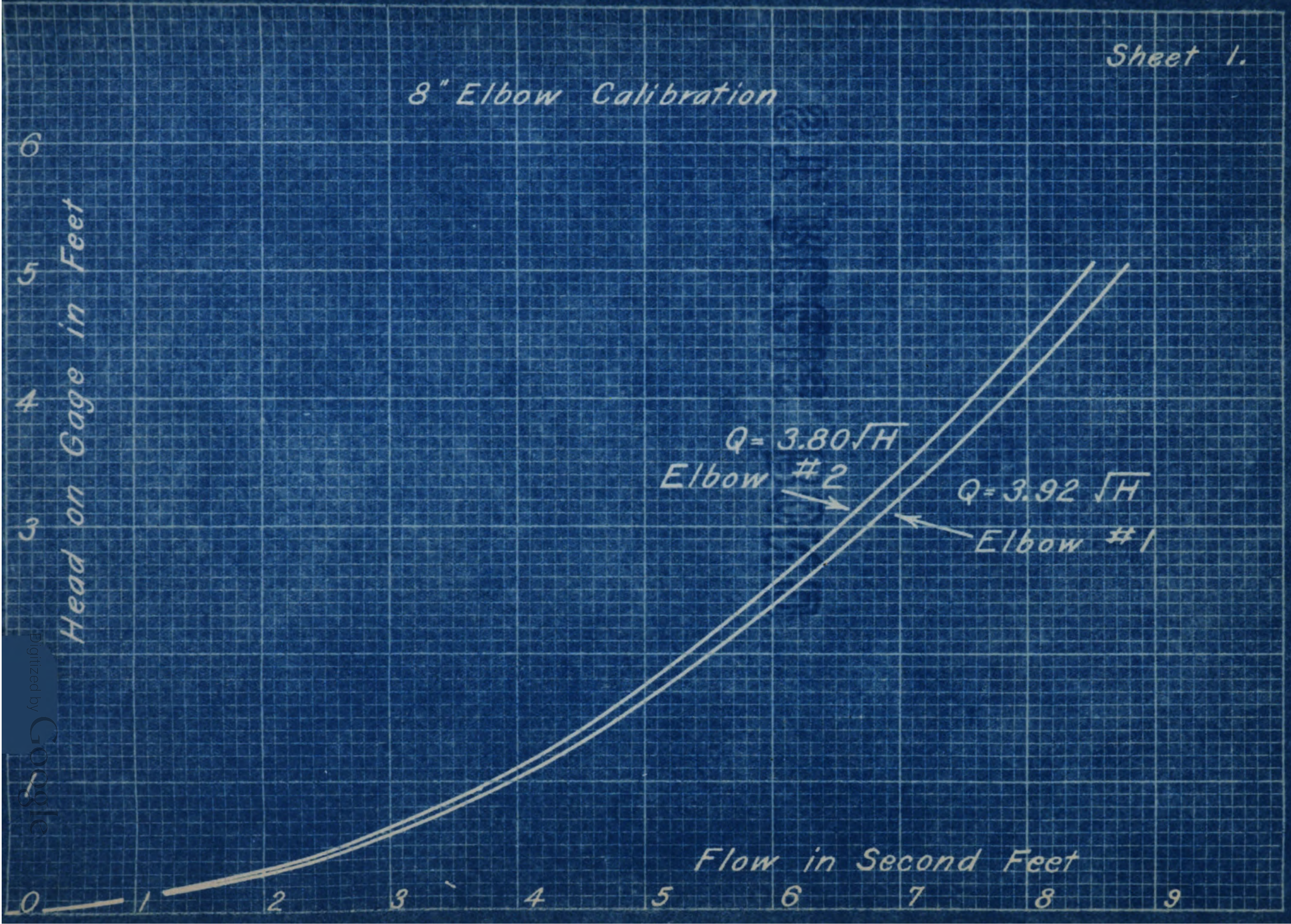
Scale 1" = 6'-0"



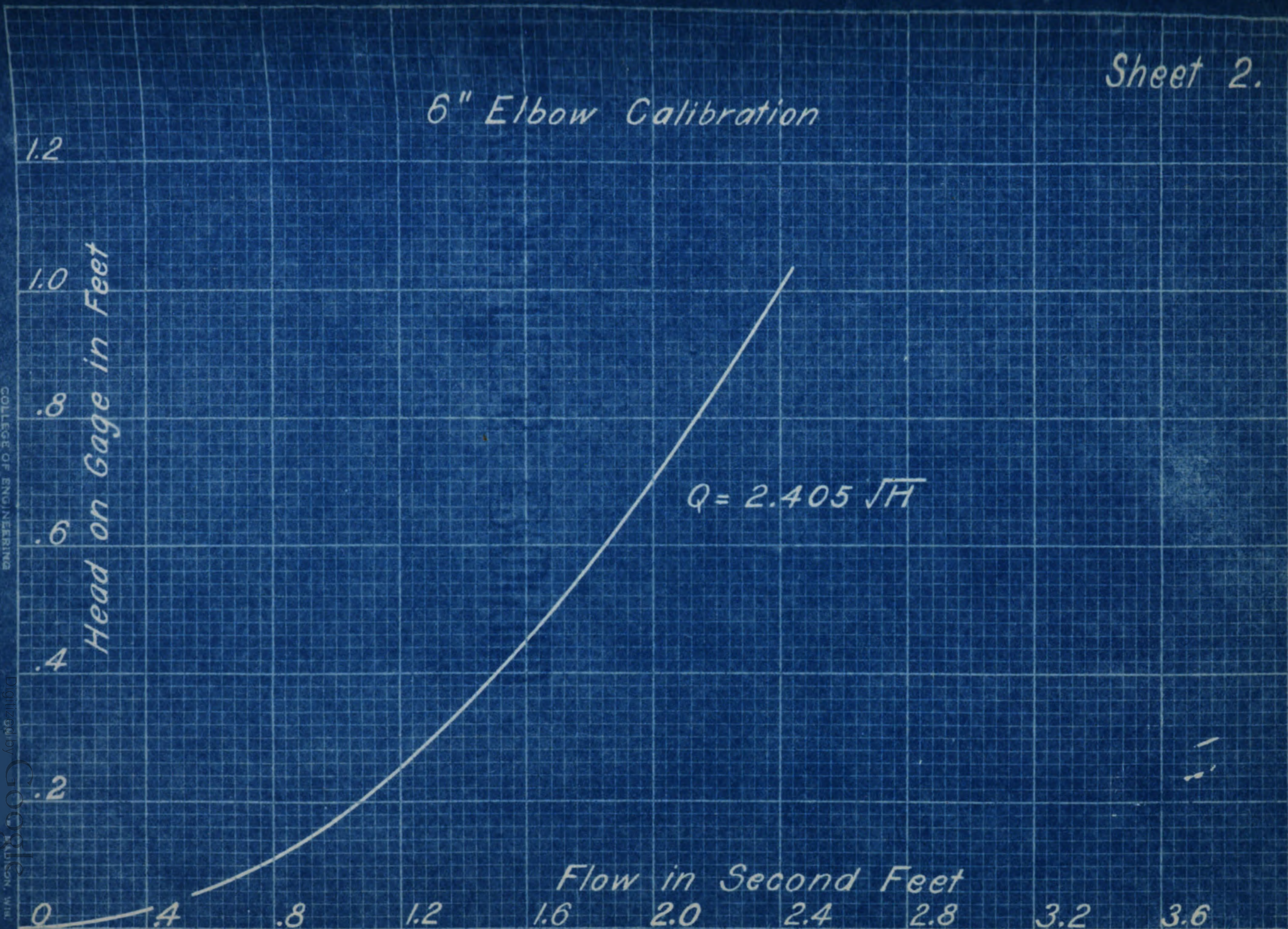


Plan

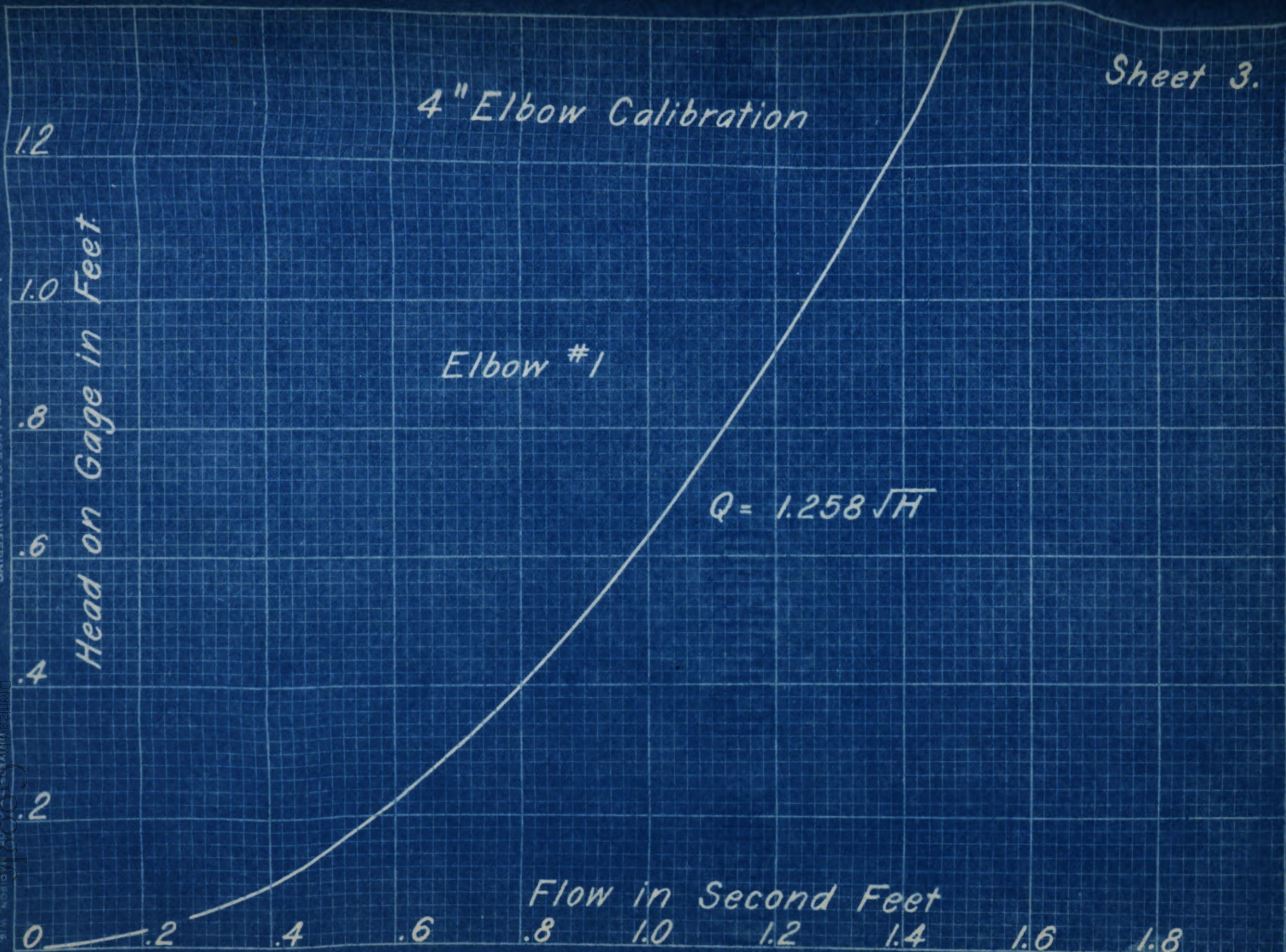
Diagrams of Apparatus

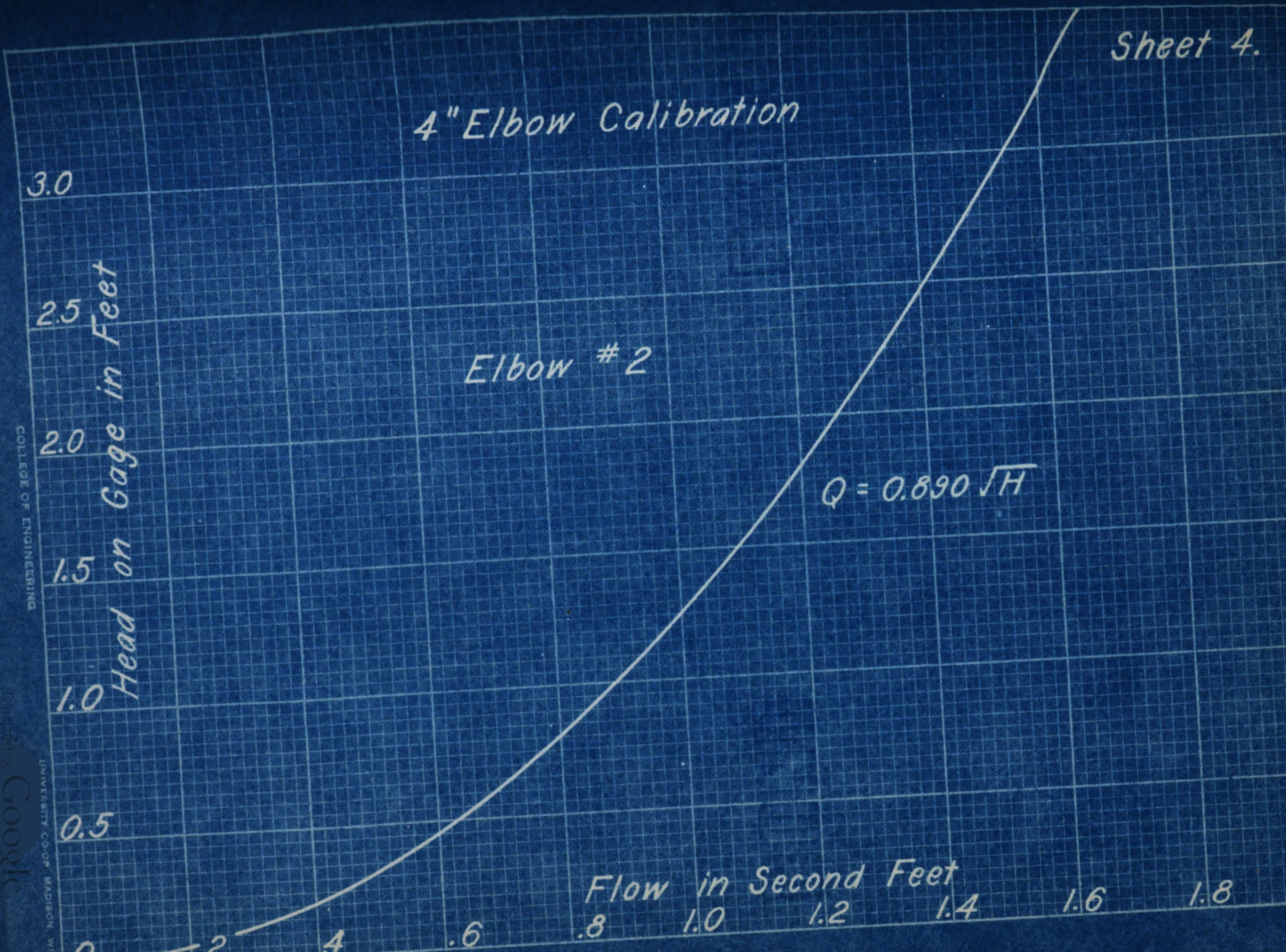


Sheet 1.
8" Elbow Calibration
Q = 3.80√H
Elbow #2
Q = 3.92 √H
Elbow #1
Head on Gage in Feet
Flow in Second Feet
0
1
2
3
4
5
6
7
8
9

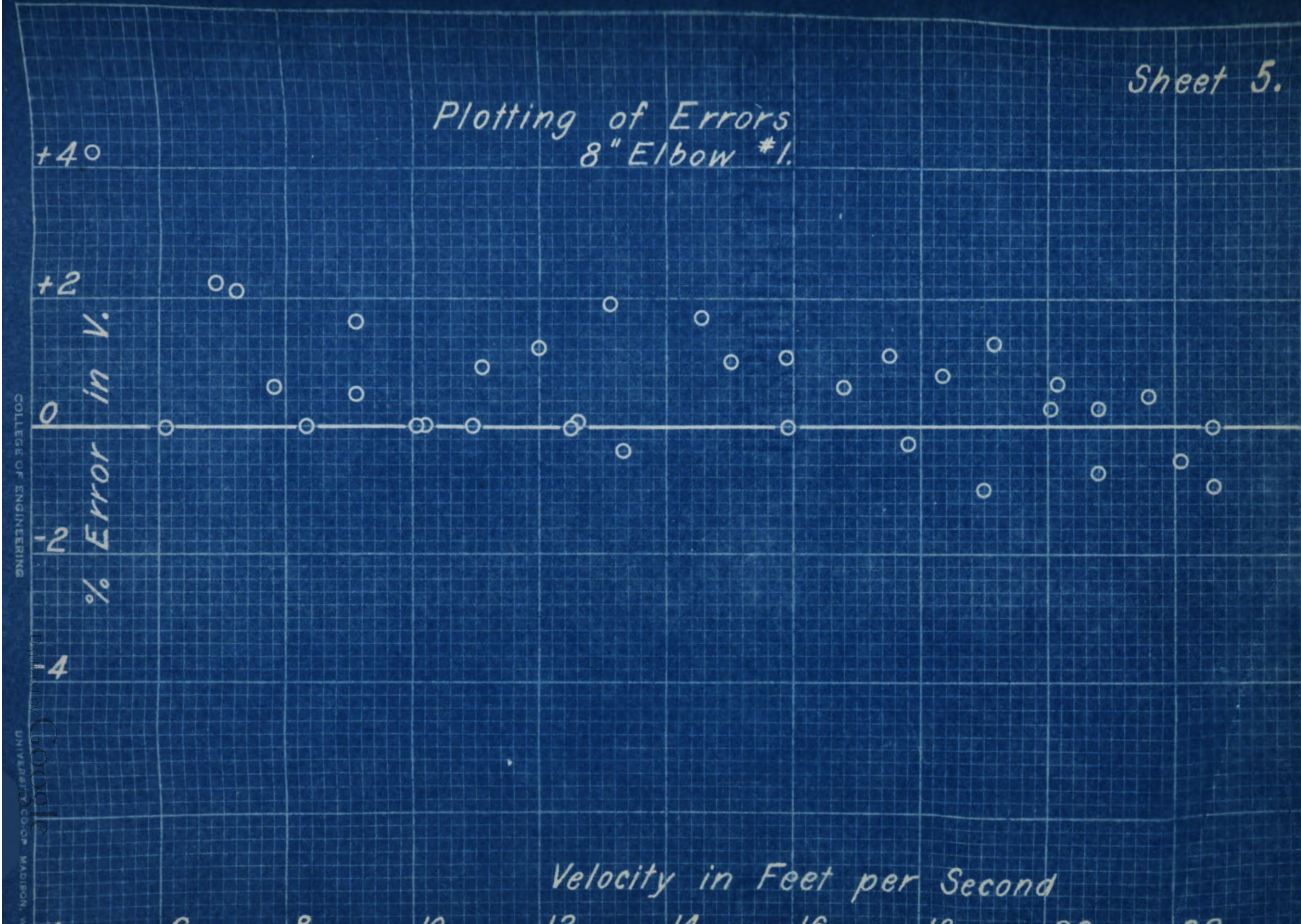


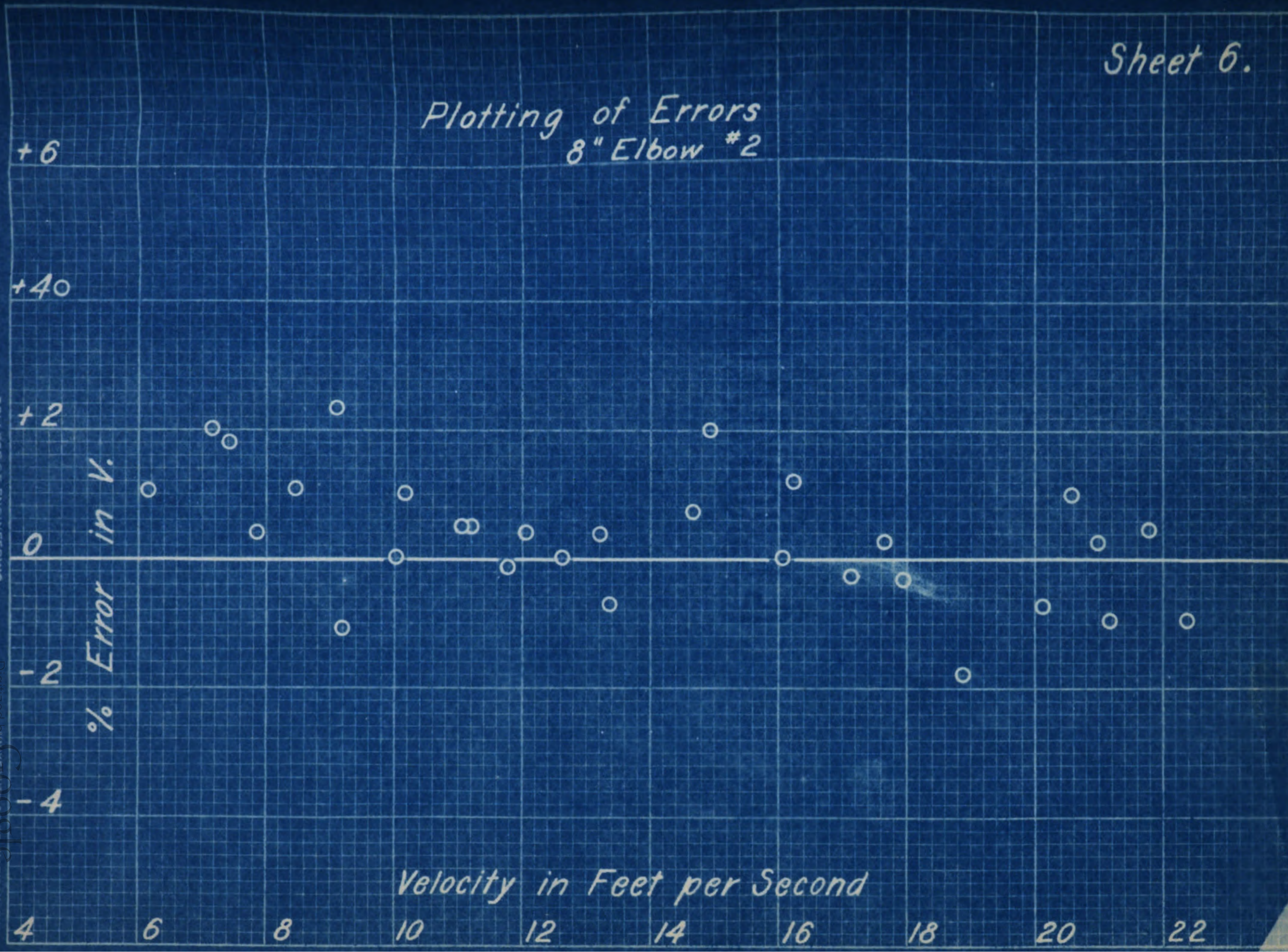
FORM C2
Sheet 2.
6" Elbow Calibration
Q = 2.405 √H
Head on Gage in Feet
Flow in Second Feet
0
.2
.4
.6
.8
1.0
1.2
.4
.8
1.2
1.6
2.0
2.4
2.8
3.2
3.6


Sheet 3.
4" Elbow Calibration
Elbow #1
Q = 1.258 √H
Head on Gage in Feet
0
.2
.4
.6
.8
1.0
1.2
Flow in Second Feet
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

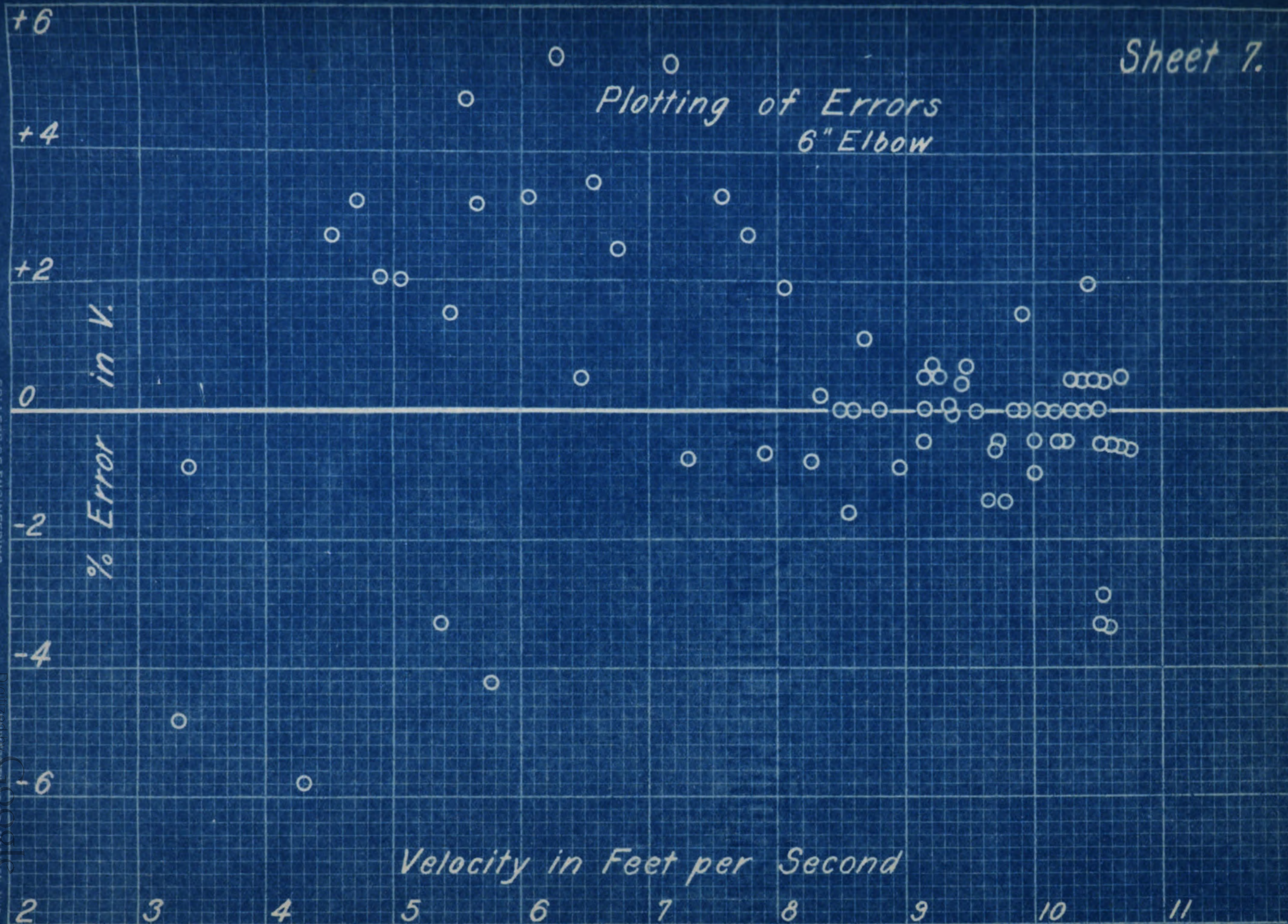


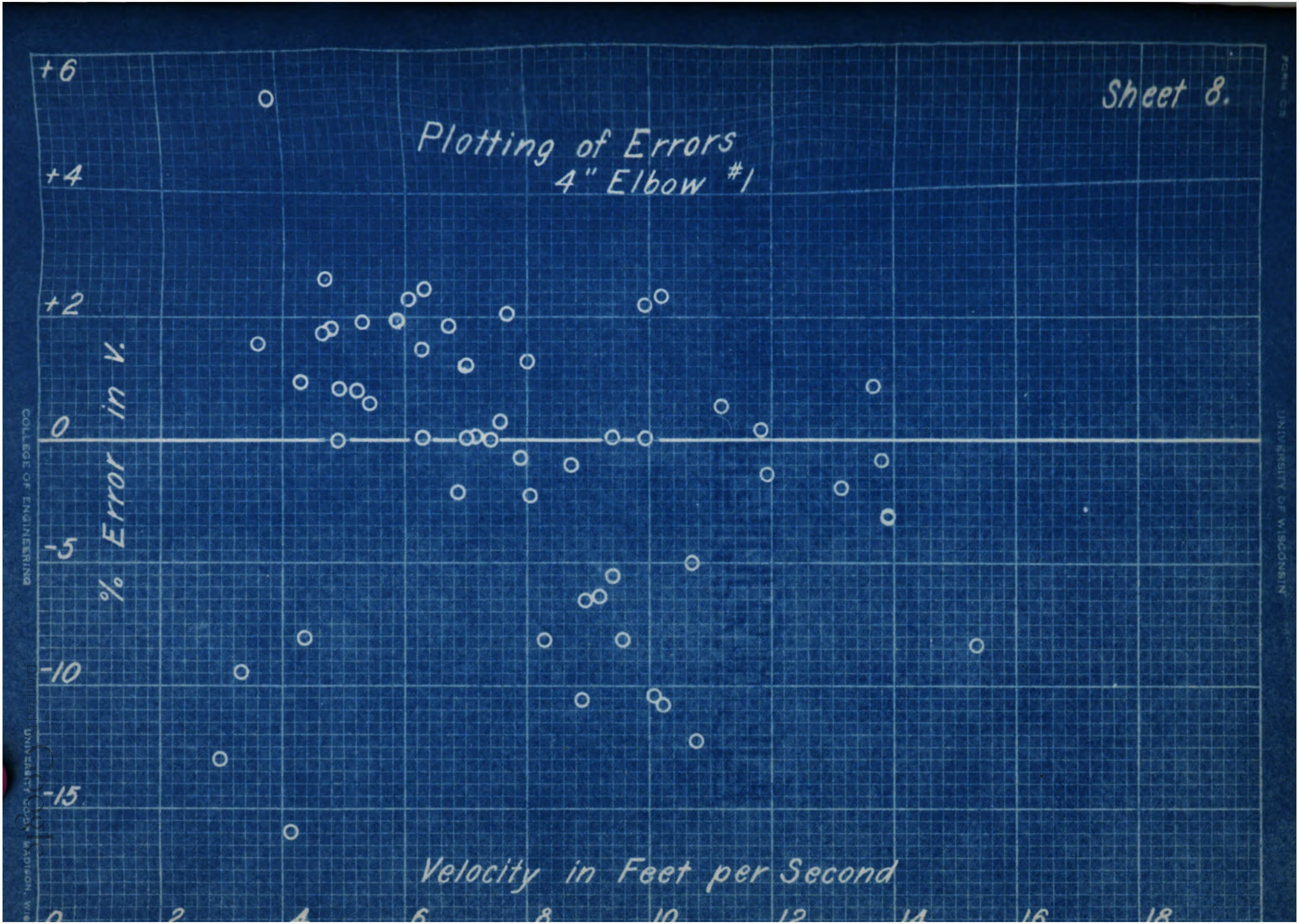
Sheet 4.
4" Elbow Calibration
Elbow #2
Q = 0.890 √H
Head on Gage in Feet
3.0
2.5
2.0
1.5
1.0
0.5
0
Flow in Second Feet
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8


Sheet 5.
Plotting of Errors
8" Elbow #1.
+4
+2
0
-2
-4
% Error in V.
Velocity in Feet per Second

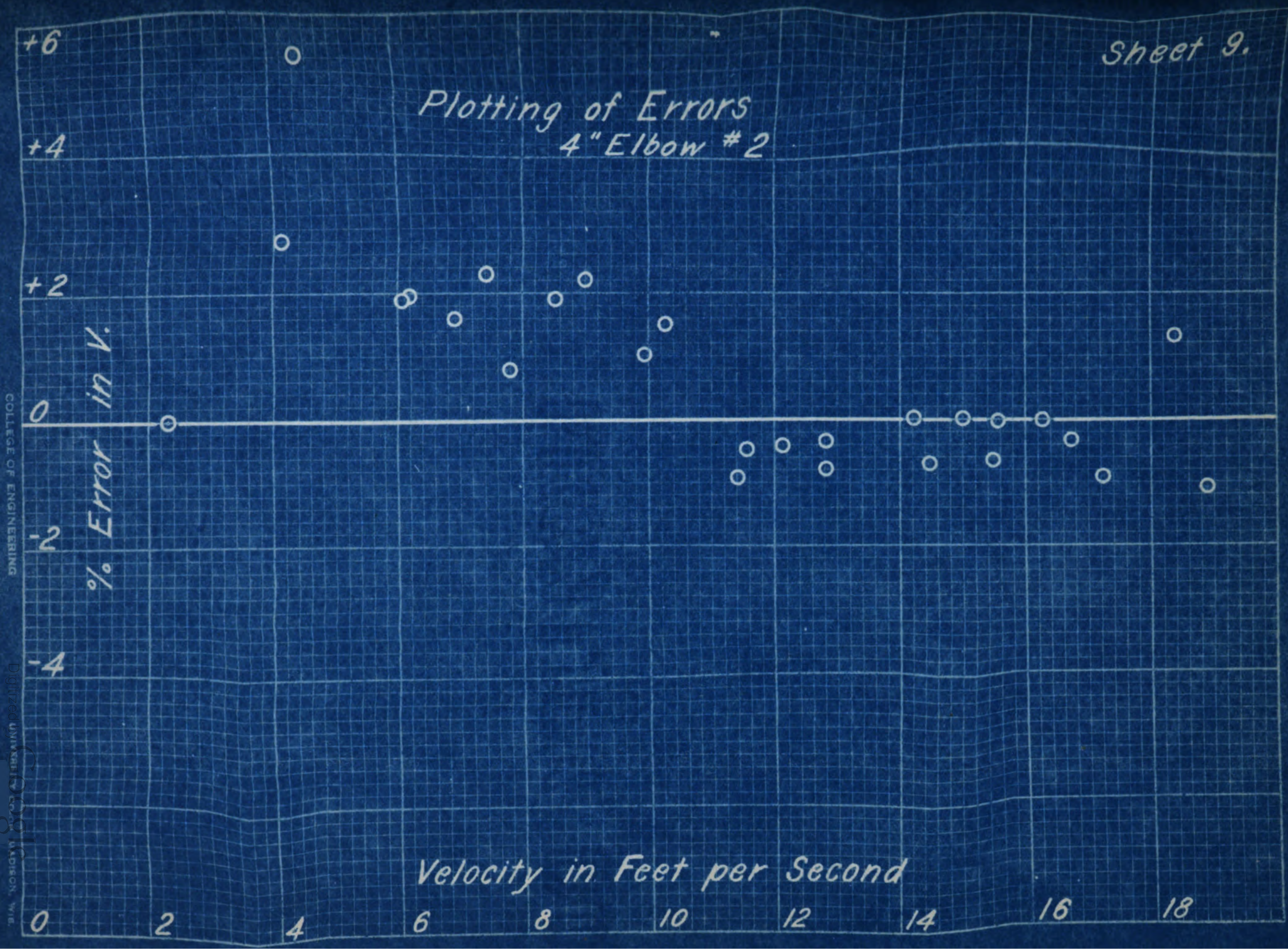


Sheet 6.
Plotting of Errors
8" Elbow #2
% Error in V.
+6
+4
+2
0
-2
-4
Velocity in Feet per Second
4
6
8
10
12
14
16
18
20
22

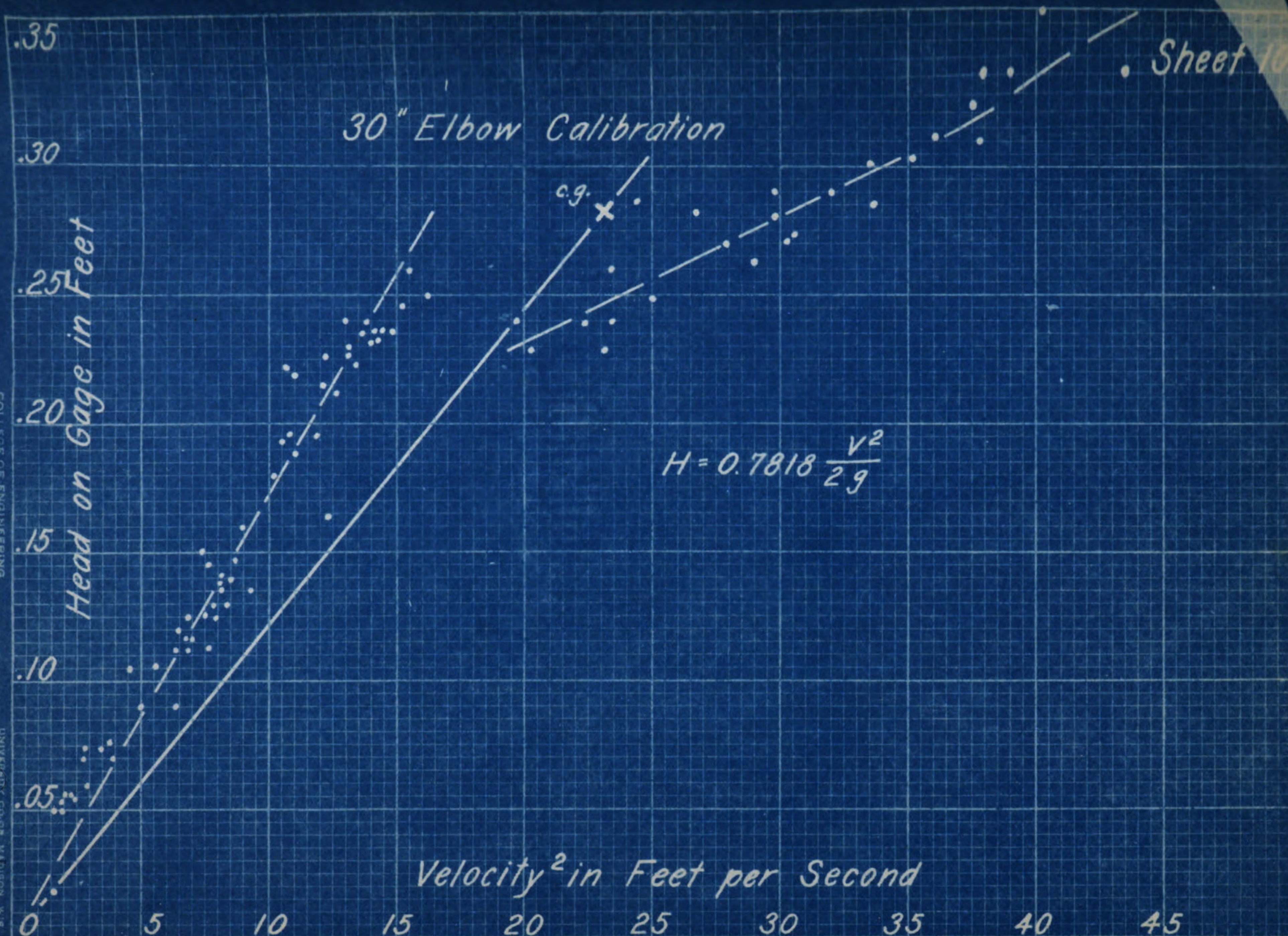

Sheet 7.
Plotting of Errors
6" Elbow
% Error in V.
Velocity in Feet per Second
+6
+4
+2
0
-2
-4
-6
2
3
4
5
6
7
8
9
10
11



UNIVERSITY OF WISCONSIN
Sheet 8.
Plotting of Errors
4" Elbow #1
% Error in V.
+6
+4
+2
0
-5
-10
-15
Velocity in Feet per Second
0
2
4
6
8
10
12
14
16
18
COLLEGE OF ENGINEERING

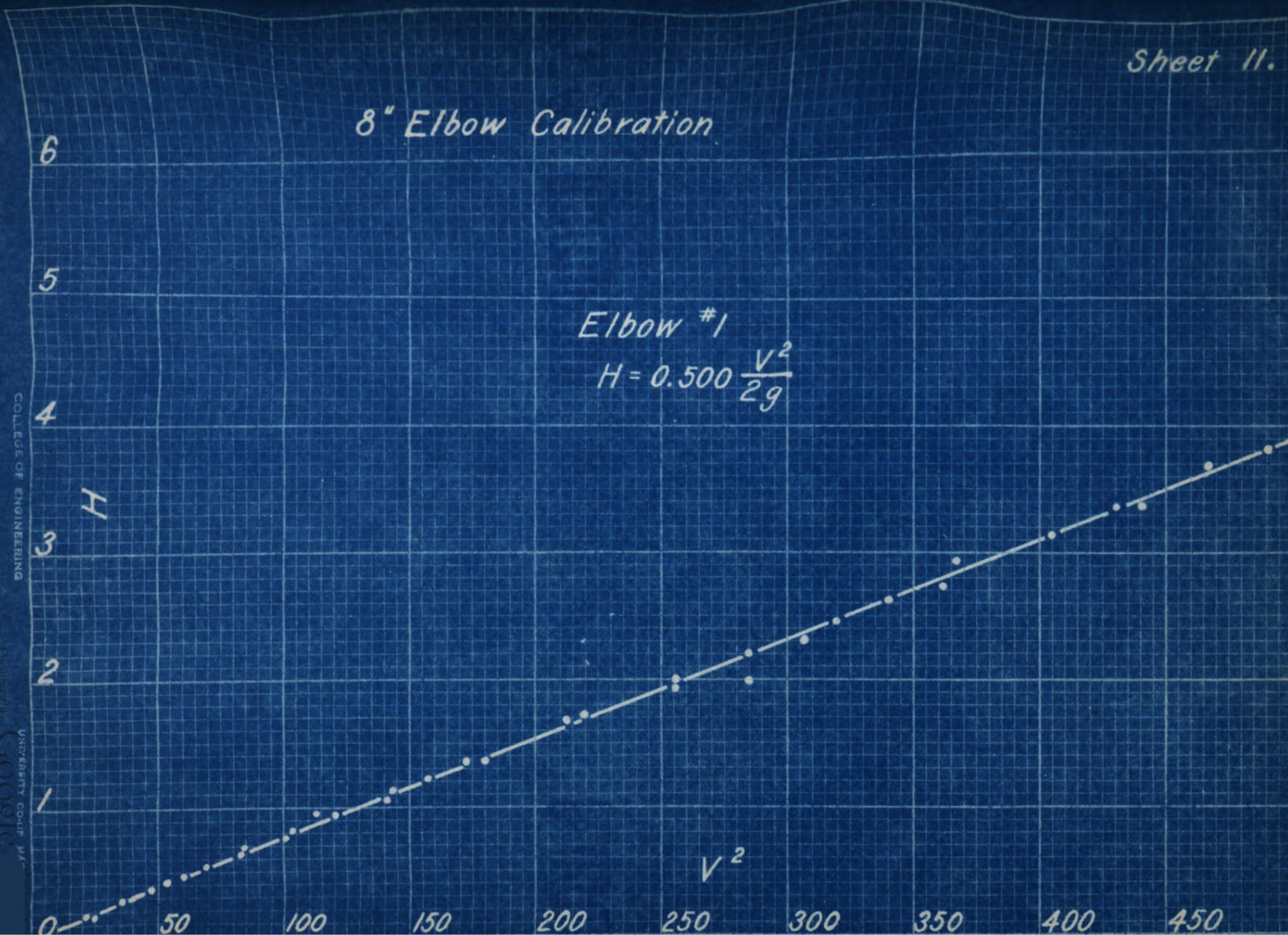


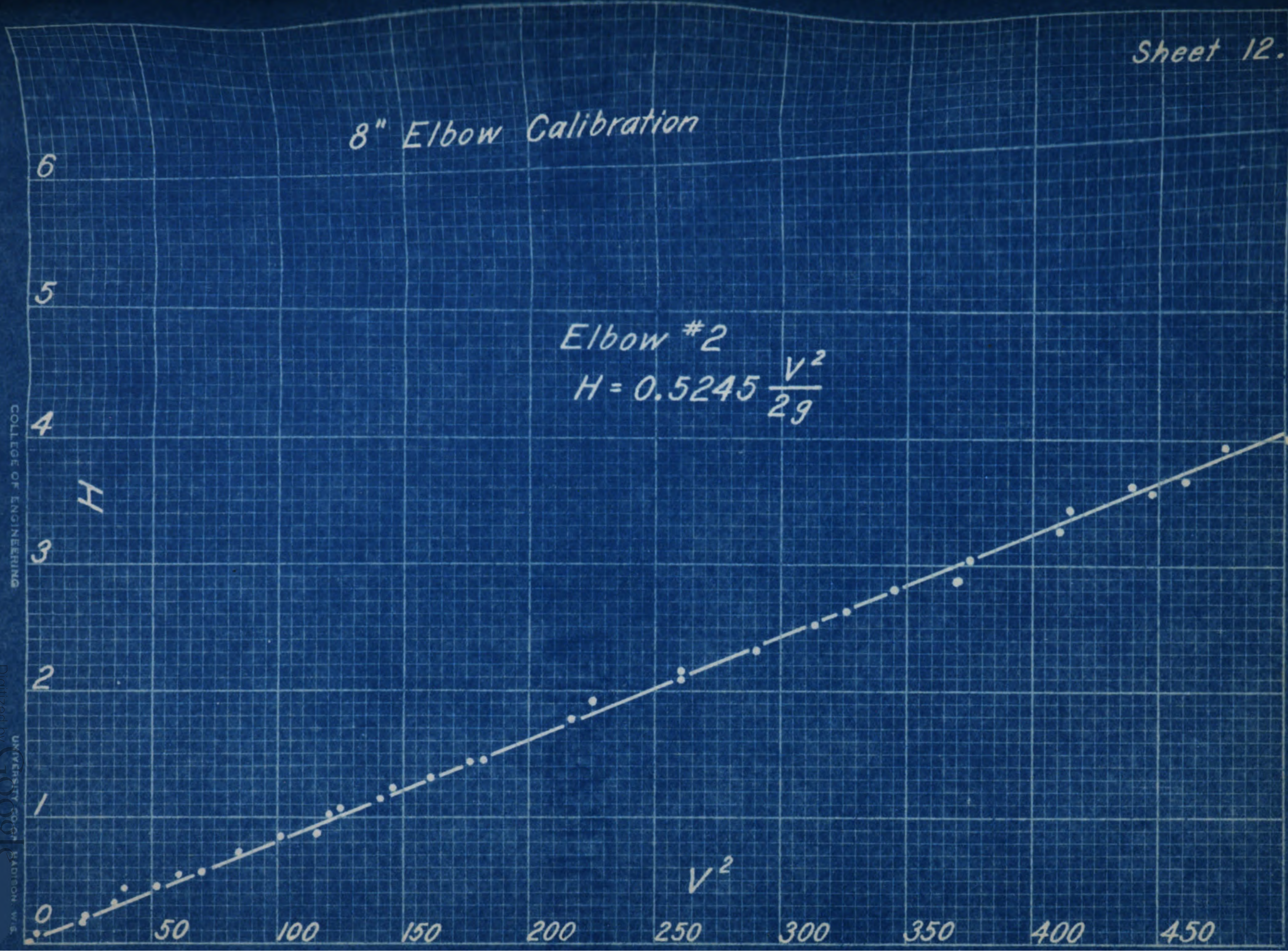
Sheet 9.
Plotting of Errors
4" Elbow #2
% Error in V.
Velocity in Feet per Second
+6
+4
+2
0
-2
-4
0
2
4
6
8
10
12
14
16
18

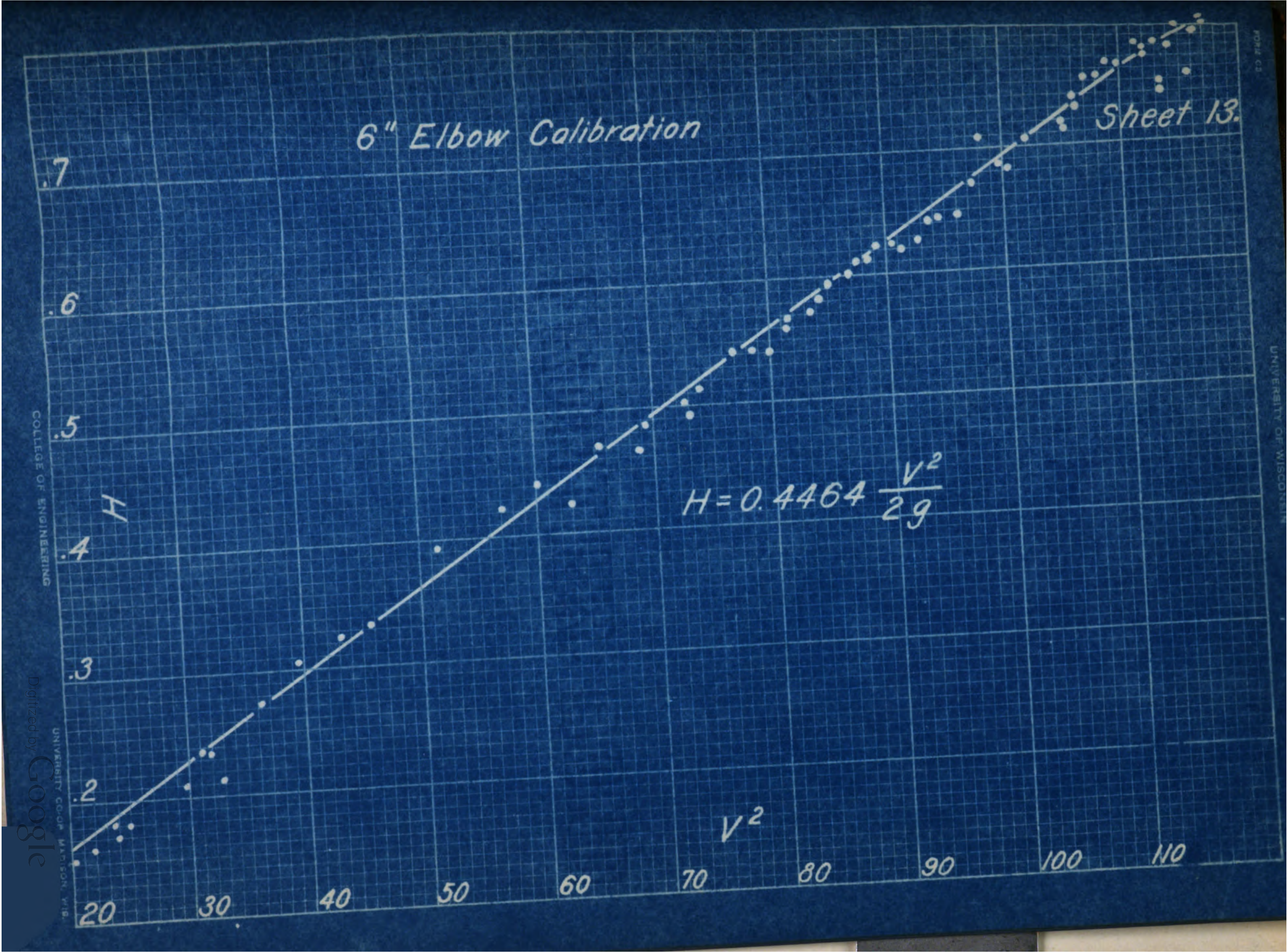


COLLEGE OF ENGINEERING

UNIVERSITY CO-OP. MADISON, WIS.


Sheet 11.
8" Elbow Calibration
Elbow #1
$H = 0.500 \frac{V^2}{2g}$
H
V^2
0
1
2
3
4
5
6
50
100
150
200
250
300
350
400
450
COLLEGE OF ENGINEERING
UNIVERSITY CO-OP


Sheet 12.
8" Elbow Calibration
Elbow #2
$H = 0.5245 \frac{V^2}{2g}$
H
V^2
0
1
2
3
4
5
6
50
100
150
200
250
300
350
400
450



UNIVERSITY OF WISCONSIN
FORM C2
6" Elbow Calibration
Sheet 13.
$H = 0.4464 \frac{V^2}{2g}$
H
.7
.6
.5
.4
.3
.2
V^2
20
30
40
50
60
70
80
90
100
110
COLLEGE OF ENGINEERING
UNIVERSITY CO-OP. MADISON, WIS.